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OCCURRENCE OF *POMATOSCHISTUS MINUTUS* (PALLAS, 1770) (PISCES: GOBIIDAE) ALONG THE NORTH AEGEAN COAST OF TURKEY

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ABSTRACT

The sand goby (Pomatoschistus minutus) *is a scarcely documented gobiid of Turkey, whose reliable occurrence records are confined to the Black Sea and Sea of Marmara. 69 specimens were recently collected off the northern Aegean Sea coasts, representing the first record of the species in the locality.*

Key words: *Pomatoschistus minutus*, Gobiidae, Aegean Sea, Turkey

RITROVAMENTO DI *POMATOSCHISTUS MINUTUS* (PALLAS, 1770) (PISCES: GOBIIDAE) IN ACQUE DELLA COSTA SETTENTRIONALE EGEA DELLA TURCHIA

SINTESI

Il ghiozzetto minuto (Pomatoschistus minutus) *è una specie di gobidi raramente documentata per la Turchia, i cui ritrovamenti attendibili sono confinati al Mar Nero e al Mar di Marmara. Sessantanove esemplari sono stati recentemente raccolti nelle acque antistanti la costa settentrionale del mare Egeo e rappresentano il primo ritrovamento di tale specie in questa località.*

Parole chiave: *Pomatoschistus minutus*, Gobiidae, mare Egeo, Turchia

INTRODUCTION

Pomatoschistus is the dominant gobiid genus of the Mediterranean and eastern Atlantic coasts of Europe, represented by 11 species inhabiting mostly marine and estuarine environments (Miller, 1986). Data on this group of fishes are remarkably scarce especially in the eastern Mediterranean basin, since they are generally overlooked due to their small sizes, cryptic and epibenthic habits. A total of four species were listed from Turkish coasts (Bilecenoglu *et al.*, 2002), and a new record *(Pomatoschistus quagga)* has recently been added to the local ichthyofauna (Fricke *et al.*, 2007). Apart from sporadic occurrence records, status and actual distribution of *Pomatoschistus spp.* in Turkey is yet to be resolved. Recent studies conducted along the northern Aegean Sea coasts have revealed the presence of a sand goby population, *Pomatoschistus minutus* (Pallas, 1770), whose occurrence in the area had previously been questionable.

MATERIALS AND METHODS

Samples were collected with a beach seine from sandy shallow waters (<2 m), Saros Bay, Turkey (40°35′0.6′′ N, 26°50′15.0′′ E; Fig.1), during February 2007. Surface water temperature was 10.7°C, with salinity reaching 27.0 ppt on the sampling day. Fish were anesthetized with tricaine methanesulphonate (MS-222) before being fixed in 4% buffered formalin. Five fish were stained with potassium permanganate ($KMnO_4$) for scale count, sensory papillae analyses and photography.

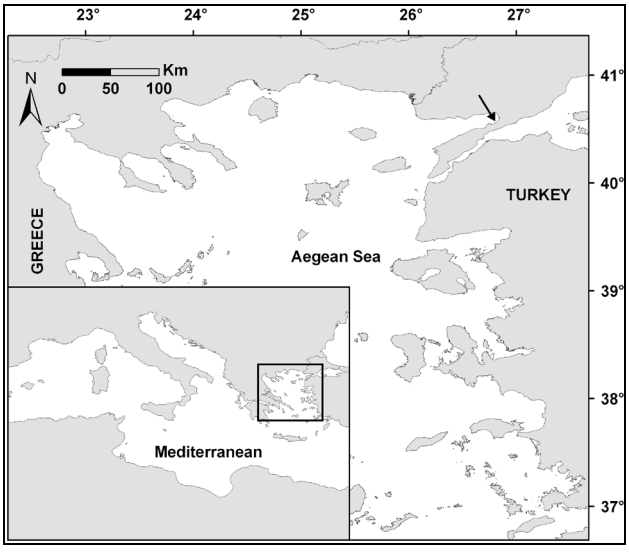

Fig. 1: Sampling locality of** Pomatoschistus minutus **(indicated with arrow).
Sl. 1: Vzorčišče peščenega glavačka** Pomatoschistus minutus **(označeno s puščico).

Terminology of the lateral line system follows Miller (1986). Two fish were dissected for vertebral count. Some of the specimens were fixed in 70% ethanol and preserved in the Piri Reis Marine Museum of Canakkale Onsekiz Mart University, Canakkale (6 females, 10 males; catalogue number PRM-PIS/2007-0055) and in the Fisheries Faculty Museum, Ege University, Bornova, Izmir (7 males, 3 females, catalogue number ESFM-PIS/07-1).

RESULTS AND DISCUSSION

Males (n = 51) ranged between 47 and 57 mm SL (mean ± SD = 49.5 ± 2.97 mm), the females (n = 18) between 46 and 56 mm SL (mean ± SD = 51.6 ± 2.26 mm). Meristic characters were: first dorsal finrays VI, second dorsal finrays I + 9–11, anal finrays I + 10–11, pectoral finrays 18–20, lateral line scales 56–62 (ctenoid). Breast and predorsal area with cycloid scales. Vertebral counts of two dissected fish were 32. The distribution of head sensory papillae of neuromasts (Fig. 2) were similar to the description of Miller (1986). Suborbital row *a* had several (9–12) short transverse rows. Row *b* extended forward to below half of the eye. Only transverse row *cp* descended below row *d* in most of the specimens. One individual, however, had row *c*8 passing through row *d* on the left side (with 12 *c* rows) but not on the right side (with 9 *c* rows). As described by Webb (1980), row *i* and supralabial section of *d* (d^1 in figure 2) were double layered. Head canals included pores σ, λ, κ, α, ρ, ρ^1, ρ^2, γ, δ, and ε. Both sexes generally had a sandy-grey colour. The males had four vertical dark bars, dark edged anal fins, dark pelvic fin, and spot on the rear of the first dorsal fin with a black-to-blue colour encircled with white. Females were pale with conspicuous dark chin blotch, some spots along the lateral line, and lacked spot on the first dorsal fin. Pelvic membrane had villous anterior edge in both sexes. Branchiostegal membrane attached to the anterior half side of isthmus.

Systematics of the *Pomatoschistus minutus* complex, including *P. minutus*, *P. lozanoi* and *P. norvegicus*, has not been settled as yet (Huyse *et al.*, 2004). Small body size and superficial resemblance to each other appears to be a conspicuous problem in precise species identification. Main characters that distinguish *P. minutus* from other species of the complex are as follows (Miller, 1986): sub-orbital row *b* extending forwards to below anterior half of eye (ending anteriorly under rear half of eye in *P. norvegicus),* suborbital transverse rows with only *cp* extending below row *d* (sub-orbital transverse rows with two extending downwards through or below level of row *d* in *P. lozanoi).*

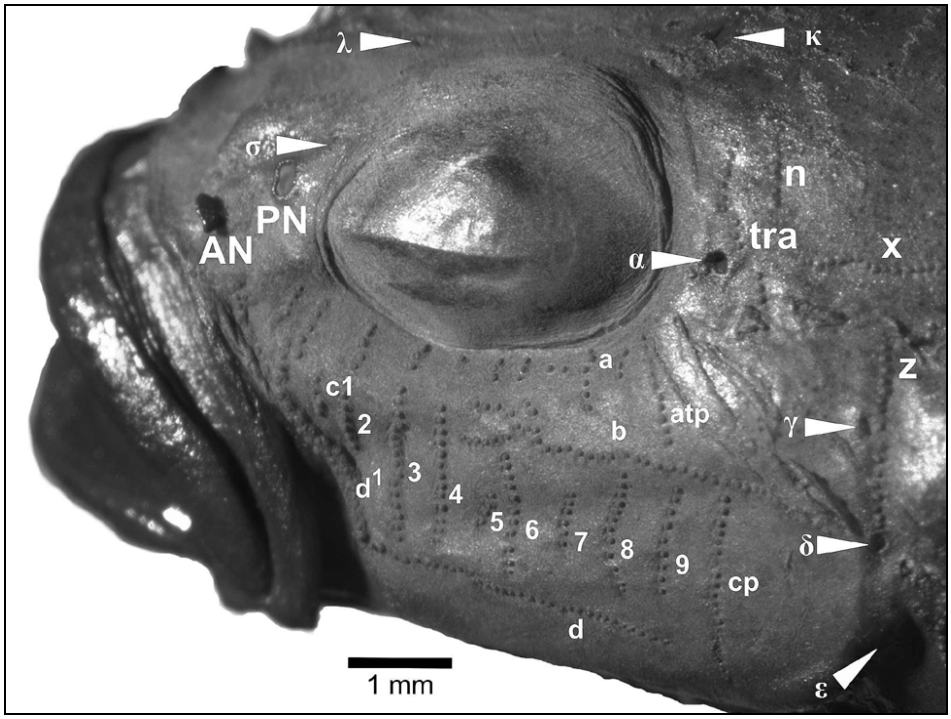

Fig. 2: Head sensory papillae of** Pomatoschistus minutus **from the northern Aegean Sea, Turkey. Legend: AN – anterior nostrils; PN – posterior nostrils; (σ, λ, κ, α) – anterior oculoscapular canal pores; (γ, δ, ε) – preopercular canal pores; (b, d, x) – longitudinal rows; (cp, n, z) – transverse rows; (a) – suborbital rows.
Sl. 2: Čutilne bradavice na glavi peščenega glavačka** Pomatoschistus minutus **iz severnega Egejskega morja, Turčija. Legenda: AN – sprednji nosnici; PN – zadnji nosnici; (σ, λ, κ, α) – sprednje očesno-ramenske kanalne pore; (γ, δ, ε) – kanalne pore na predpoklopcu; (b, d, x) – vodoravni nizi; (cp, n, z) – navpični nizi; (a) – podočesni nizi.

The two subspecies previously described, *P. minutus minutus* in the Atlantic and *P. minutus elongatus* in the Mediterranean and Black Seas, seem to be invalid based on recent researches. Although female sand gobies had eggs developed in their ovaries and nuptial coloration was apparent on the male samples, we were unable to find any breast pigmentation in these mature samples in both sexes. Since this pigmentation is supposed to be present in *P. minutus elongatus*, our observation supports the findings of Stefanni *et al*. (2003) who suggested that the differentiation in the two subspecies, *P. minutus minutus* and *P. minutus elongatus*, is questionable based on their genetic analyses. However, the dark chin blotch was evident in female samples as is supposed to be a colour character for the subspecies *P. minutus elongatus*. Except for one specimen, who had only one ω pore on the left side, we were not able to detect the pore ω on the head canals for the other 68 specimens. Similarly, Stefanni (2000) did not detect any pore ω on the head canal in the Mediterranean population of another *Pomatoschistus,* the closely related Norway goby, *P. norvegicus* (Collett, 1903). This pore is supposed to be present in both species according to Miller (1986).

Previous occurrence records of *P. minutus* from Turkey are based on a few scattered studies, majority of which lack detailed species descriptions. Ninni (1923) was the first who recorded the species from Turkey, based on material collected from the Sea of Marmara. Sözer (1941) gave a concise description of sand goby from the same locality. The first Turkish Black Sea record was given by Erazi (1942), who also confirmed the presence of *P. minutus* in the Sea of Marmara. Considering that the species originated from the Mediterranean Sea, Erazi (1942) and Slastenenko (1956) indicated the possible occurrence of *P. minutus* in Aegean and Mediterranean Seas as well, although their assumption was not based on actual specimen collection and examination from these sites. The most reliable record of sand goby from the Aegean Sea was presented by Fage (1918), who found a single specimen (45 mm total length) from Saronikos Gulf of Greece (37° 51′ N, 23° 14′ E). It should be noted, however, that neither Tortonese (1975) nor Miller (1986) included the Aegean Sea within the known distribution range of *P. minutus*. In some recent ichthyoplankton studies *(i.e.* Hossucu & Ak, 2002), a dense postlarval distribution of sand goby was mentioned from Izmir Bay (central Aegean Sea coast of Turkey). Despite the several inventory studies carried out in Izmir Bay, no adult sand goby specimens could be found (see Bilecenoglu *et al.,* 2002), and this locality is

characterized by the well established population of *P. marmoratus*. Absence of the latter species in the ichthyoplankton list of Hossucu & Ak (2002) might be an indication of a misidentification. Since there is a lack of goby-oriented research in the Aegean Sea, further detailed studies may reveal a larger distribution range for *P. minutus*.

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POJAVLJANJE PEŠČENEGA GLAVAČKA *POMATOSCHISTUS MINUTUS* (PALLAS, 1770) (PISCES: GOBIIDAE) VZDOLŽ SEVEROVZHODNE OBALE TURŠKEGA DELA EGEJSKEGA MORJA

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POVZETEK

Peščeni glavaček (Pomatoschistus minutus) *je redko dokumentirana vrsta iz družine glavačev v turških vodah, saj je bil zanesljivo zabeležen le v Črnem in Marmarskem morju. Pred kratkim pa je bilo v obrežnih vodah severnega Egejskega morja ujetih kar 69 primerkov peščenega glavačka, kar je prvi zapis o tej vrsti na tej lokaliteti.*

Ključne besede: *Pomatoschistus minutus*, Gobiidae, Egejsko morje, Turčija

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FIRST RECORD OF *CORIS JULIS* IN THE MIRAMARE NATURAL MARINE RESERVE

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ABSTRACT

Since 1975, counts of fish fauna have been regularly carried out in the Miramare Natural Marine Reserve by the visual census technique. During these years, it has been possible to observe the evolution of the ecosystem. In September 2006, the first sighting of Coris julis *occurred, a species never previously observed in the protected area. The presence of this species was also reported in the summer 2007 census.*

Key words: *Coris julis*, Miramare Natural Marine Reserve, first report

PRIMA SEGNALAZIONE DI *CORIS JULIS* NELLA RISERVA NATURALE MARINA DI MIRAMARE

SINTESI

Dal 1975 all'interno della Riserva Naturale Marina di Miramare sono stati effettuati regolarmente conteggi delle specie ittiche presenti con la tecnica del "visual census". In questi anni è stato possibile osservare l'evoluzione dell'ecosistema. Nel Settembre del 2006 è avvenuto il primo avvistamento di Coris julis*, una specie mai osservata prima all'interno dell'Area Marina Protetta. La presenza di questa specie è stata segnalata anche nel monitoraggio dell'estate 2007.*

Parole chiave: *Coris julis*, Riserva Naturale Marina di Miramare, prima segnalazione

INTRODUCTION

The geographical position of the northern end of the Gulf of Trieste, where the Miramare Marine Protected Area (MPA) is situated (Fig. 1), and its environmental factors make this area an important observatory for biodiversity. Observation and monitoring stations have been established not only within the protected area, but also at other important coastal stations in the Gulf of Trieste, as well as in agreement with Slovenian scientific staff (NIB, Marine Biology Station of Piran). The check lists of species associations are compared in order to obtain evaluations of the spatial and time changes since 1975 (Bussani & Feoli, 1975). During these years, it has thus been possible to record the new occurrences of these species in the Miramare Natural Marine Reserve and in the Gulf of Trieste in the database of the "Littoral Observatory" (O.d.L. – Osservatorio del Litorale) (Castellarin *et al.*, 2001).

Many species and associations differ in their distribution: in substantial regressions *(i.e. Fucus virsoides),* although in rapid reappearance as well *(i.e. Cymodocea nodosa* or *Cystoseira* spp.). In many cases, these dynamics are likely caused by meteorological and climate factors that can influence water replacement in the persistence of high temperatures in some portions of the water column by the presence and/or development of planktonic spores, eggs, larvae and juveniles coming from the eastern coast.

In September 2006, the first sighting of *Coris julis* was made, a species never previously observed in the protected area (Castellarin *et al.*, 2001), as the water temperature during the winter is too low for its requirements. The presence of this species was also reported during the summer 2007 census.

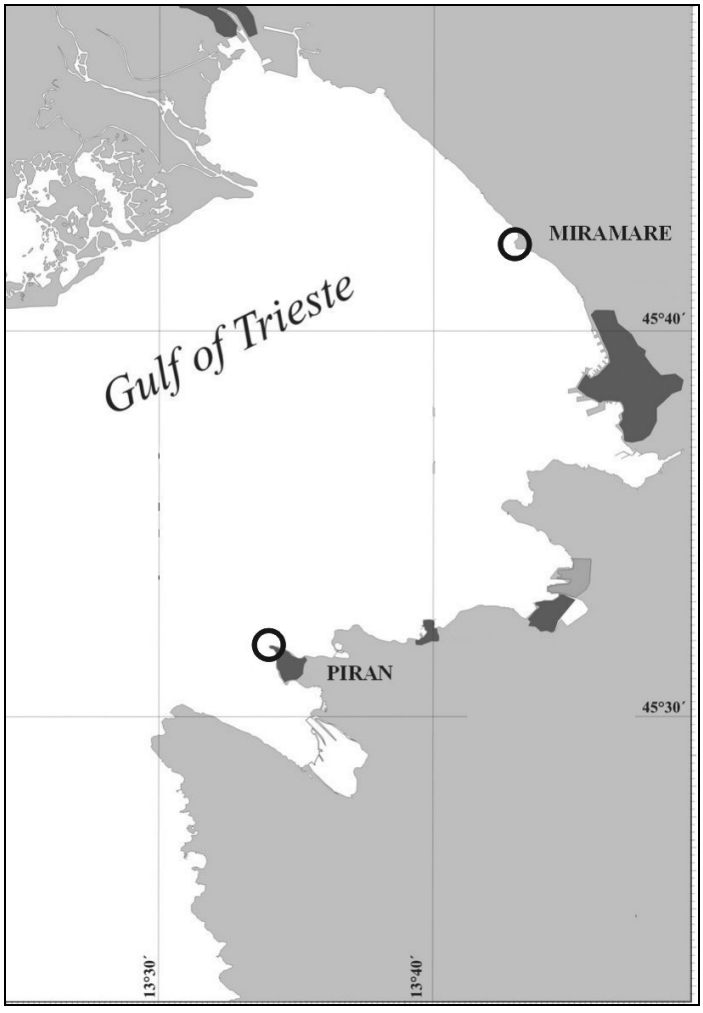

Fig. 1: Map showing locations of the Miramare Natural Marine Reserve and Piran.
Sl. 1: Zemljevid z označenima lokacijama Naravnega morskega rezervata Miramare in Pirana.

MATERIALS AND METHODS

The area considered in this study is the Miramare Natural Marine Reserve (Fig. 1) in the Gulf of Trieste, which is the northernmost part of the Adriatic Sea. The area is 30 ha wide with 1.8 km long coastline.

The technique of visual census was used to obtain a continuous characterization of the fish community and its modifications inside the protected area and at several points of the Gulf of Trieste. The fieldwork was carried out with the aid of scuba diving and snorkelling: data were collected *in situ* using the transect technique and point visual, non-destructive diving visual census methodology (Harmelin-Vivien *et al.*, 1985; Vacchi & La Mesa, 1999; De Girolamo & Mazzoldi, 2001). The monitoring activity by visual census inside the Protected Area began in 1975, when the first compilation of the list of species living in the area was developed (Bussani & Feoli, 1975; Bussani, 1976; Castellarin *et al.*, 2001). The studies carried out after 1983 (Morin & Spoto, 1984), report that since that year, from April to October, at least three monitoring activities a month were performed. In fact, for some years, the continuation of studies during the winter was not reported: this factor is considered to be irrelevant for the aim of this study owing to the temperature ranges between summer and winter, typical of the Trieste Gulf. The temperature data from 1977 to 2007 were collected with the OCEAN SEVEN 316 CTD multiparameter probe (temperature accuracy of 0.003°C and resolution of 0.0005°C) at the C1 station located along the boundary of the Miramare Marine Protected Area at 45°41′58′′ N, 13°42′21′′ E.

RESULTS

Coris julis (Fig. 2), a single male specimen, was first observed in the Miramare Marine Reserve in September 2006. With three observation activities for each day of monitoring, the frequency of this species in 2006 was 18 sightings out of the 90 observations performed. In the winter months, however, its presence was not recorded. In 2007, including all monitoring activities performed to date (January to May), a total of 19 sightings out of 36 observations were recorded.

C. julis is a fish belonging to the Labridae family, living in the Mediterranean Sea and along the North African and European Atlantic coasts. This species is hermaphrodite protogynic and reproduces during the summer, laying spherical pelagic eggs. This species eats invertebrates such as sea urchins, small shellfish and other organisms, which it finds by digging in the sand. Its range is in the coastal area, from the surface to a depth of 120 meters, although it is found usually at about 60 meters. *C. julis* is easily approached while diving, also because it finds food in the sediment moved by the divers. It prefers habitats rich in seaweed and prairies of *Posidonia oceanica*, but the main limiting factor for its distribution is the temperature. It can live in a temperature range from 6.7 to 28.4°C, but its ideal range is between 17.6°C and 27.8°C. At night and mainly during the winter it seems to live under the sand, with only its head protruding. Its preferred salinity ranges between 28.5 and 39 psu, but it more commonly occurs between 31.4 and 38.1 psu (www.fishbase.com). Even though the area considered in this study belongs to the Mediterranean

Fig. / Sl. 2: *Coris julis* ***(Linnaeus, 1758). (Photo / Foto: E. Balasso)***

Sea, the northern Adriatic is a unique entity considering that it has temperature and salinity values different from the rest of the Mediterranean Sea. This occurs because the Adriatic Sea is a muddy-sandy plain, with a sea bottom that in the Gulf of Trieste does not exceed 25 meters in depth. This low depth favours strong water heating during the summer (the temperature can reach 27–28°C) and strong water cooling during the winter, with values that usually fall under 8°C.

As mentioned above, the main obstacle to the arrival of thermophilic species is the significant temperature range that brings the winter temperature below 6.5°C. Therefore, a contextual analysis of the information was necessary before reporting, considering the historical series of the number of days/year, from 1930 to 1995, when values under 6.5°C were recorded in the Gulf of Trieste by the Sta. Molo Sartorio (Stravisi, 1983; Stravisi, 2000; Orel & Zamboni, 2001; Odorico *et al.*, 2006). The frequency of these events of water cooling actually shows a significant decrease, mainly in the last 40 years. From 1935 to 1964, the water column temperature dropped below 6.5°C for an average of 13 days/year. In comparison, between 1965 and 1974, this occurred only 1 day/year. In the period of 19 years from 1975 to 1994, the water column cooling dropped under 6.5°C for an average of 3 days/year. The data collected in C1 from 1977 to 2007 showed that in the last 7 years the temperature in January and February has not fallen below 7°C.

In the Gulf of Trieste, *C. julis* has never been seen prior to 1998, even in Piran that is located in its southern part (L. Lipej, *pers. comm.)*. The last visual census study performed in three Slovenian Marine Protected Areas related the density of *C. julis* in Fiesa-Pacug (unprotected area) of 0.08 (±0.21)/100 m^2 (Lipej *et al.*, 2003).

DISCUSSION

The prediction of Grainger (1992) is apparently becoming a reality in the Adriatic Sea: that the foreseen global warming would make southern species extend their range northward. This hypothesis is supported by many monitoring activities in the Adriatic Sea, where it is reported that the warm water species were recently found in greater numbers in the northern sectors and also that some species have been found occurring for the very first time (Dulčić *et al.*, 1999; Dulčić & Grbec, 2000).

The first observation of *Coris julis* in the Miramare Natural Marine Reserve in September 2006 also supports the hypothesis of the expansive northward movement of thermophilic species and changes in marine biodiversity studied in the northern Adriatic Sea (Dulčić *et al.*, 2004). The data previously reported are in fact also in accordance with the study carried out in 2004 regarding the new species recorded on the other side of the Adriatic Sea, whereby the northward spread of thermophilic species has been considered as an indirect indication of the Adriatic and Mediterranean water warming (Dulčić *et al.*, 2004).

Moreover, the frequent observations performed along the Trieste coast and the collaboration with Slovenian scientific staff (Castellarin & Odorico, 1999) over the years have already facilitated the survey of species that slowly move from Croatian and Slovenian coasts to the Italian coasts. The updating of the flora-fauna census performed in the Miramare Natural Marine Reserve in 1995 (Odorico, 1995) recorded the first observation of *Haliclona mediterranea*, which occurred in June 1994, and this had been related to the development of Coralligenous by the rocks. Only one year later, in 1995, during the study on the "Effects of full fishing prohibition on the fish population in the Miramare Marine Reserve" (De Girolamo *et al.*, 1996), *Tripterygion delaisi* was also included in the flora-fauna census.

The historical series of data surveyed over the years have allowed monitoring of the ecosystem evolution, with continuous comparisons among individual years. We concentrate on the studies "Monitoraggio Biologico e Visual Census anno 2000" (Odorico *et al.*, 2000) and "Report Interno per il Ministero dell'Ambiente, 2002" (Castellarin, 2002), where the historical data were integrated with the monitoring activities in the field (visual census, checks on steady stations, microspecimens and videotransect) and with the information achieved by surveying the chemical-physical data.

It is necessary to consider that in last year the first sighting occurred in September, whereas in 2007 it occurred in May, which is much earlier. With future surveys it will be possible to understand whether *C. julis* is a species living in the protected area of Miramare or if it is a chance observation of a single specimen that had migrated northwards.

PRVI PODATEK O POJAVLJANJU KNEZA *CORIS JULIS* V NARAVNEM MORSKEM REZERVATU MIRAMARE

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POVZETEK

V Naravnem morskem rezervatu Miramare na Tržaškem poteka štetje ribje favne z vizualno tehniko štetja že vse od leta 1975. V teh letih je bilo mogoče opaziti določene spremembe v ekosistemu. Septembra 2006 je bil v rezervatu prvič opažen knez Coris julis*, vrsta, ki tu prej ni bila še nikoli registrirana. Sicer pa je bilo pojavljanje kneza zabeleženo tudi med štetjem ribje favne poleti 2007.*

Ključne besede: *Coris julis*, Naravni morski rezervat Miramare, prvo pojavljanje

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NEW RECORDS OF SOME RARE AND LESS-KNOWN FISHES IN THE GULF OF TRIESTE (NORTHERN ADRIATIC)

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ABSTRACT

The authors present some data on four fish species that have up-to-date been reported as rare or at last less known rare fishes for the Gulf of Trieste. Three of them, Luvarus imperialis, Mola mola *and* Ranzania laevis*, are considered typical ocean species, whereas* Ophidion barbatum *is a less-known and overlooked fish species with particular habitat demands.*

Key words: new records, *Luvarus imperialis, Mola mola, Ranzania laevis, Ophidion barbatum*, Gulf of Trieste

NUOVE SEGNALAZIONI DI SPECIE ITTICHE RARE E POCO CONOSCIUTE NEL GOLFO DI TRIESTE (ADRIATICO SETTENTRIONALE)

SINTESI

Gli autori riportano nuovi dati inerenti quattro specie ittiche, che fino ad oggi sono state considerate specie rare o perlomeno poco conosciute nel Golfo di Trieste. Tre di queste, Luvarus imperialis, Mola mola *e* Ranzania laevis *vengono considerate tipiche specie oceaniche, mentre* Ophidion barbatum *è una specie poco conosciuta e trascurata, con esigenze particolari nella scelta dell'habitat.*

Parole chiave: nuove segnalazioni, *Luvarus imperialis, Mola mola, Ranzania laevis, Ophidion barbatum*, Golfo di Trieste

INTRODUCTION

Although the research on ichthyofauna in the Gulf of Trieste has more than a centennial tradition, the area has been receiving rather poor scientific attention in terms of a wider ichthyologic research. The knowledge of marine fish fauna is therefore considered still to be fairly scarce. In this regard it still happens that some new, rare or less-known species are reported for the area. To this end, we would like to present new data on four more or less rare fish species, recently caught in the Gulf of Trieste.

Some authors presented a list of fishes, based mainly on species found at the Trieste market (probably with supposition that the majority of them had been caught in the Gulf of Trieste) (for example Stossich, 1876; Faber, 1883; Graeffe, 1906), while some other presented check-lists of fishes of the Slovenian part of the Gulf of Trieste (Lipej, 1999; Marčeta, 1999). Some new (Lipej *et al.*, 1996; Parenti & Bressi, 2001; Lipej *et al.*, 2005) and rare species (Bettoso & Dulčić, 1999) for the Adriatic were noted from the Gulf of Trieste.

During comprehensive surveys of ichthyofauna, certain rare or less known fish species were recorded. The aim of this paper is to present new data on four more or less rare fish species, recently caught in the Gulf of Trieste.

MATERIAL AND METHODS

The area investigated during this study includes the Gulf of Trieste (northern Adriatic Sea). During the 1995-2007 period, information on four fish species, *e.g. Luvarus imperialis, Mola mola*, *Ophidion barbatum* and *Ranzania laevis*, has been gathered from records documented by the staff of the WWF Miramare Marine Reserve (Trieste, Italy) and Marine Biology Station of the National Institute of Biology (Piran, Slovenia). The data on occurrence of the herewith studied species originated from occasional catches or underwater inspection (Fig. 1).

RESULTS AND DISCUSSION

This paper presents data on four largely rare or less-known fish species, recorded in the Gulf of Trieste during the last decade. Three of them, *Luvarus imperialis, Mola mola* and *Ranzania laevis*, are considered typical ocean species, whereas *Ophidion barbatum* is a less-known fish species with particular habitat demands.

Louvar *Luvarus imperialis* (Rafinesque, 1810)

The specimen of *L. imperialis* was caught on August 26th, 2007, in the waters off Grado by the vessel belonging to the Port Authority of Grado. It measured 120 cm TL and weighed 45 kg. Some photographs of the specimen were taken (Fig. 2). Unfortunately, the fish has been discarded.

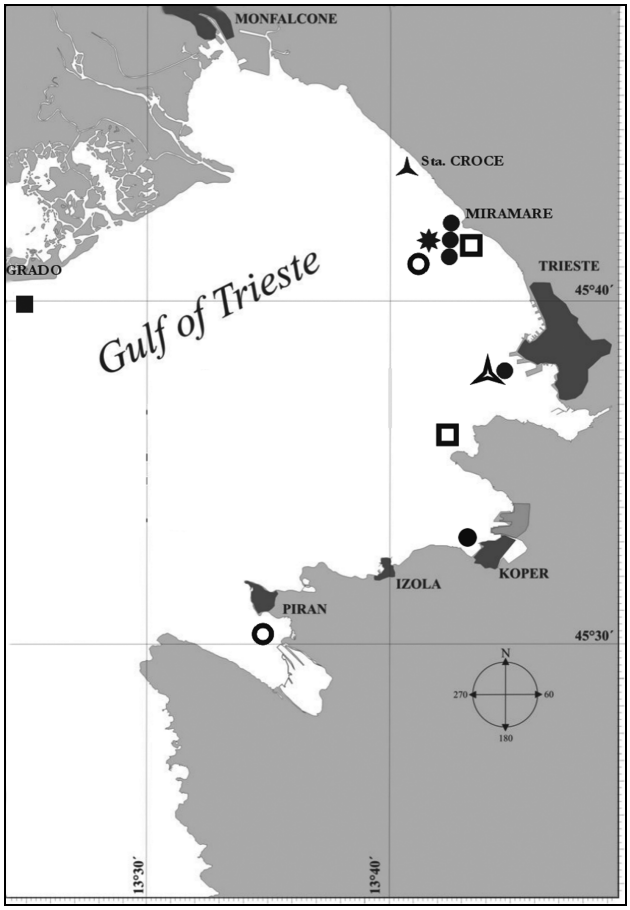

Fig. 1: Map of the Gulf of Trieste with the sites where specimens of the studied fish species were recorded. Legend: *Luvarus imperialis:* ■ ***– new record,*** □ ***– old records;*** *Mola mola:* ● ***– new records,*** ○ ***– old record;*** *Ranzania laevis:* ✦ ***– new record,*** ✧ ***– old record;*** *Ophidion barbatum* ***–*** ✸***– new record.***
Sl. 1: Zemljevid Tržaškega zaliva in lokalitete, kjer so bili ujeti ali najdeni primerki obravnavanih vrst. Legenda: *Luvarus imperialis:* ■ ***– nova najdba,*** □ ***– stari podatki;*** *Mola mola:* ● ***– nove najdbe,*** ○ ***– stari podatek;*** *Ranzania laevis:* ✦ ***– nova najdba,*** ✧ ***– stari podatek;*** *Ophidion barbatum* ***–*** ✸ ***– nova najdba.***

Stossich (1876) considered *L. imperialis* a rare and occasional species in the Gulf of Trieste. Graeffe (1906) reported on a specimen of Louvar in the Gulf of Trieste. Bussani (1980) reported on a specimen of Louvar (without any specific data) caught in the Marine protected area of Miramare on July 21st, 1977. Additional two juvenile specimens of Louvar were caught 5 Nm off Miramare in the direction of Koper Bay on the very next day. The first measured 56 cm in TL and weighed 4 kg, while the second measured 60 cm and weighed 4.30 kg (Bussani, 1980).

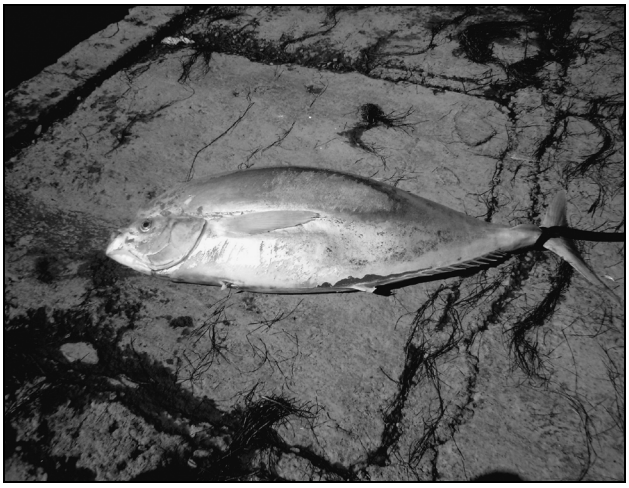

Fig. 2: A specimen of Louvar *Luvarus imperialis* ***found dead in the waters of Grado. (Photo: by courtesy of the staff of Capitaneria di porto di Grado).***
Sl. 2: Primerek pečinke *Luvarus imperialis,* ***ki so jo našli mrtvo v vodah blizu Gradeža. (Foto: z dovoljenjem posadke luške kapitanije mesta Gradeža).***

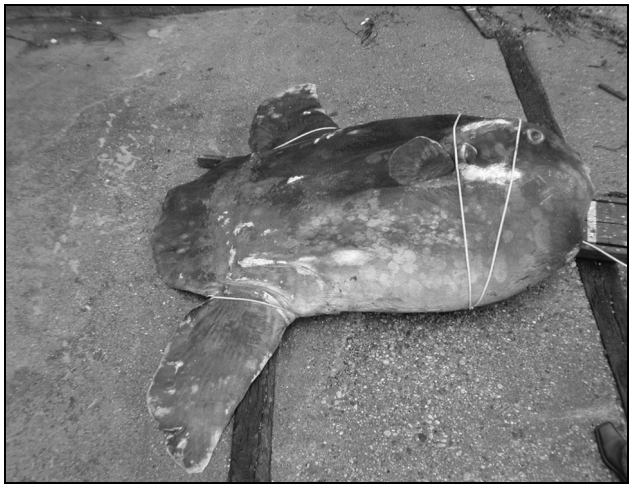

Fig. 3: Ocean sunfish *Mola mola* ***found stranded in April 2001 in the Bay of Grignano near Trieste (WWF Miramare archives).***
Sl. 3: Morski mesec *Mola mola,* ***ki je nasedel aprila 2001 v zalivu Baia di Grignano pri Trstu (arhiv WWF Miramare).***

Ocean sunfish *Mola mola* (Linnaeus, 1758)

The ocean sunfish *M. mola* has been recorded fairly frequently during the last decade. A specimen of about 1 m in length and 70 kg in weight was recorded in Koper Harbour on September 29th, 1998. The next record dates from April 2001, when a female of 200 cm TL and 400 kg was found stranded in the Baia of Grignano near Trieste. The specimen was deposited in the Museo Civico di Storia naturale di Trieste. The specimen died due to the hook, entangled in the mouth (Beraldo *et al.*, 2002). Another specimen was recorded in November of the same year at almost the same locality. It was sighted and photographed (Fig. 3), but subsequently the specimen died and eventually found stranded in the Baia of Grignano. In April 2002, at least five specimens were recorded in the northern Adriatic; one of them was found stranded in Trieste. The last record of *M. mola* dates to July 13th, 2004, when a specimen was sighted close to the shore beneath Miramare Castle.

According to Stossich (1876), *M. mola* is a rare and occasional species in the Gulf of Trieste. However, the occurrence of the ocean sunfish is much more common in the Adriatic Sea than previously thought. According to Dulčić *et al.* (2007), 43 records of ocean sunfish were made in the Adriatic Sea between 1781 and 2006. Only three specimens, however, have been mentioned in their checklist. Two specimens, one from Koper (1998) and one from Trieste (April 2002), have already been mentioned, whereas the third record is much older and refers to the specimen recorded on April 13th, 1975, in the waters near Portorož (Jardas & Knežević, 1983). On their list, several other records mentioned in this study are missing. It seems that the occurrence of sunfish is related to the warm season, since the majority of data originated from the March-November period.

Slender sunfish *Ranzania laevis* (Pennant, 1776)

A single specimen of *R. laevis* was caught in mid-June 1995 in the waters off Santa Croce Harbour (near Trieste). The slender sun fish was harpooned by a trident fishing tool called *"fiocina"*. The total length of the fish was 35 cm (Fig. 4).

This is the third record of this species for the Gulf of Trieste. The first record in the area was made by Trois (1884a, b). The second recovery of this species was reported by Specchi & Bussani (1973) for the Port of Trieste on July 21st, 1972. It measured 52 cm and weighed 4.5 kg. Although Jardas and Knežević (1983) considered *R. laevis* fairly rare and occasional fish in the Adriatic Sea, they presented a list of 16 records for the area in the ten year period from 1972 to 1982. Recently, Dulčić *et al.* (2007) presented data dealing with the occurrence of slender sunfish in the Adriatic Sea. In their list, 35 records of *R. laevis* are documented, where only a single record, the capture described by the above mentioned Specchi & Bussani (1973), is listed from the Gulf of Trieste. The data are more or less equally distributed throughout the year.

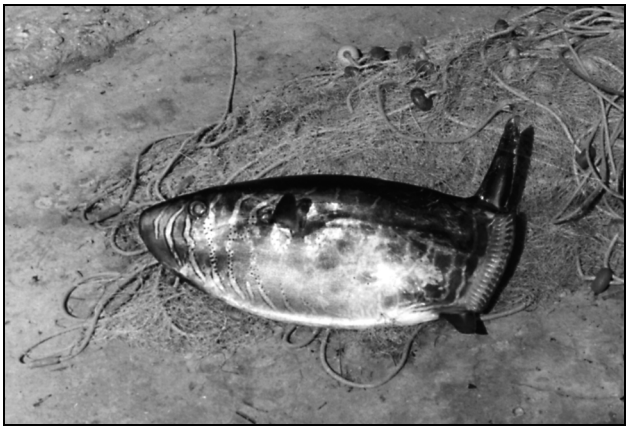

Fig. 4: A specimen of slender sunfish *Ranzania laevis* ***caught in mid-June 1995 in the waters off the Santa Croce Harbour (WWF Miramare archives).***
Sl. 4: Primerek loparja *Ranzania laevis,* ***ujetega sredi junija 1995 v mandraču Sv. Križa pri Trstu (arhiv WWF Miramare).***

Snake blenny *Ophidion barbatum* Linnaeus, 1758

On September 8th, 2007, a 16 cm TL specimen of *O. barbatum* was caught by hand by a diver swimming in the Miramare Marine Park near Trieste. The specimen was found almost dead on a sandy patch under the bedrock below Miramare Castle at 8 m depth. The specimen was photographed and subsequently released (Fig. 5).

According to Marčeta (1999), a single specimen of this species has previously been reported from the Gulf of Trieste, *i.e.* in the 19th century. Stossich (1876) considered this species more or less common, particularly in winter months. Since this nocturnal predator lives in fine sandy and muddy habitats, the species would have been probably detected more frequently with the increased sampling frequency in suitable areas, especially during the night.

Fig. 5: Snake blenny *Ophidion barbatum****, photographed on 8 September 2007 in the marine protected area of Miramare. (Photo: D. Poloniato)***
Sl. 5: Bradati huj *Ophidion barbatum,* ***fotografiran 8. septembra 2007 v podvodnem parku Miramare. (Foto: D. Poloniato).***

Possible factors affecting the occurrence of the studied species

Although the Gulf of Trieste represent the northernmost part of the Mediterranean Sea, some apparently open-water (or oceanic) marine organisms occasionally occur in this area. For example, fin whales *(Balaenoptera physalus)* and basking sharks *(Cetorhinus maximus)* have been reported on several occasions in the Gulf of Trieste during the last three decades (see for example Lipej *et al.*, 2000, 2004).

It is difficult to speculate what phenomena affected the occurrence of the three ocean fishes in the Gulf of Trieste, considering that only few specimens have been recorded. However, there is an ongoing trend in the increase of marine fish biodiversity in the Adriatic Sea (see for example Dulčić & Lipej, 2002; Lipej & Dulčić, 2004) and in the Gulf of Trieste as well. Due to the use of new techniques and increased prospection activity, some new and rare species such as *Thorogobius eppihipiatus, Millerigobius macrocephalus* and *Apletodon incognitus* have been documented for the very first time in the Slovenian part of the Gulf (Lipej *et al.*, 2005) and in the entire Gulf at the very same time as well.

Nowadays, it is well known that temperature is the main large-scale variable, known to affect fish populations (*sensu* Francour *et al.*, 1994; Dulčić *et al.*, 1999, 2004). In this respect, various cases of movements by some thermophilous southern species such as *Plectorhinchus mediterraneus* (Lipej *et al.,* 1996), *Thalassoma pavo* (Dulčić & Pallaoro, 2002), *Sphoroides pachygaster* (Dulčić, 2002) and others have been already documented in the Adriatic Sea as well. According to Dulčić *et al.* (2007), the occurrence of *M. mola* coincides with sea warming. The same could be said of the herewith mentioned records of this species, as well as of the other two species, *R. laevis* and *L. imperialis.*

It should be pointed out that "rarity" is a subjective and elastic term varying with place, even such a small area as is the Gulf of Trieste, and moreover it is subject to change with our increasing knowledge of the fauna. According to Morović (1973), the rarity of certain fish species could be evaluated from the records in scientific literature. The same author proposed three possibilities regarding rarity. If the species is recorded fewer than five times, it should be treated as a very rare species. If up to ten records have been made, then the species is considered to be rare, whereas fish species caught in certain areas but only in specific season should be treated as fairly rare. According to the proposed criteria, we could

say that *L. imperialis, R. laevis* and *O. barbatum* (at least nowadays) could be treated as very rare, and *M. mola* as a rare species in the Gulf of Trieste. If we take into account the entire Adriatic area, Jardas (1985) considered *L. imperialis* and *O. barbatum* rare species, whereas *M. mola* and *R. laevis* are interpreted as fairy rare Adriatic species.

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NOVE NAJDBE NEKATERIH REDKIH IN MANJ ZNANIH RIB V TRŽAŠKEM ZALIVU (SEVERNI JADRAN)

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POVZETEK

Navzlic stoletni tradiciji je Tržaški zaliv z ihtiološkega vidika še vedno razmeroma slabo raziskan. Še vedno se dogaja, da v ta najsevernejši predel Sredozemskega morja zaidejo nekatere vrste rib, ki so redke ali slabo poznane. V tem prispevku navajamo najdbe o štirih vrstah rib, ki so bile doslej komajda kdaj evidentirane v Tržaškem zalivu. Tri od teh, pečinka (Luvarus imperialis), *morski mesec* (Mola mola) *in lopar* (Ranzania laevis), *so značilne oceanske vrste, huj* (Ophidion barbatum) *pa je manj znana in prezrta ribja vrsta s posebnimi zahtevami glede izbire habitata. Na podlagi novih najdb in dosedanjih zapisov lahko pečinko, loparja in huja opredelimo kot zelo redke vrste z manj kot petimi zapisi o pojavljanju v Tržaškem zalivu, morski mesec pa kot redko vrsto.*

Ključne besede: nov zapisi, *Luvarus imperialis, Mola mola, Ranzania laevis, Ophidion barbatum*, Tržaški zaliv

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FIRST RECORD OF *CARCHARHINUS BRACHYURUS* (GUNTHER, 1870) (CHONDRICHTHYES; CARCHARHINIDAE) FROM SARDINIAN WATERS (CENTRAL MEDITERRANEAN)

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ABSTRACT

The authors report on the first record of Carcharhinus brachyurus *(Gunther, 1870) (Chondrichthyes; Carcharhinidae) from Sardinian waters registered in the Sardinian Large Elasmobranch Database (S.L.E.D.). A female carcharhinid shark, measuring 253 cm total length, was caught in June 2005 in a tuna net off San Pietro Island (south-western Sardinia, Italy, Mediterranean Sea), and was later identified as* C. brachyurus *from photographs based on its dentition and some morphological features.*

Key words: *Carcharhinus brachyurus,* distribution, Sardinian Large Elasmobranch Database (S.L.E.D.), Mediterranean Sea

PRIMA SEGNALAZIONE DI *CARCHARHINUS BRACHYURUS* (GUNTHER, 1870) (CHONDRICHTHYES; CARCHARHINIDAE) PER LE ACQUE DELLA SARDEGNA (MEDITERRANEO CENTRALE)

SINTESI

Viene presentata la prima segnalazione di Carcharhinus brachyurus *(Gunther, 1870) (Chondrichthyes; Carcharhinidae) per le acque della Sardegna, registrata nel Sardinian Large Elasmobranch Database (S.L.E.D.). La segnalazione è relativa ad un esemplare femmina di carcarinide di cm. 253 di lunghezza totale, catturato nel giugno del 2005 nelle reti della tonnara dell'Isola di San Pietro (Sardegna sud-occidentale, Italia, mediterraneo) e identificato successivamente come* C. brachyurus *sulla base di fotografie evidenzianti la dentatura ed alcuni parametri morfometrici.*

Parole chiave: *Carcharhinus brachyurus,* distribuzione, Sardinian Large Elasmobranch Database (S.L.E.D.), Mediterraneo

INTRODUCTION

The Copper Shark or Bronze Whaler, *Carcharhinus brachyurus* (Gunther, 1870), is both an epipelagic and insular shark species, occurring predominately in warm temperate and subtropical waters of all oceans (Garrick, 1982; Compagno, 1984b; Compagno *et al.*, 2005), including the Mediterranean Sea (Serena, 2005). The presence of this species in the Mediterranean basin was confirmed in 1981 (Cigala Fulgosi, 1983), while its presence in the Mediterranean had been suspected since the 19th century (Garrick, 1982; Orsi Relini, 1998).

Recently, the distribution of *C. brachyurus* in the Mediterranean basin has been defined with more precision, thanks to records in the scientific literature. Besides the historical records concerning some specimens coming from the northwestern Mediterranean Sea (Nice, France), and one from the northern Adriatic Sea (Garrick, 1982), there are more recent records from Palma de Mallorca in the Balearic Islands (Morey & Massuti, 2003), the Ligurian Sea (Vacchi *et al.*, 1996), the southern Tyrrhenian Sea (Zava *et al.*, 2006), the Sicilian Channel (Cigala Fulgosi, 1983), the Algerian coast (Hemida *et al.*, 2002), and from the Dodecanese Islands (Fergusson, 1994).

This note is the thirty-seventh record of *C. brachyurus* from the Mediterranean Sea (Zava *et al.*, 2006), but the very first from Sardinian waters recorded in the Sardinian Large Elasmobranch Database (S.L.E.D.), furthering our knowledge on the distribution of this species in the Mediterranean Sea. The prime objective of this project, which is carried out by the "DNAquA – Laboratorio di ricerche e studi sulla vita marina" and other independent researchers is to collect historical and recent data on elasmobranch species occurring in Sardinian waters.

MATERIALS AND METHODS

In the afternoon of June19th, 2005, a female *Carcharhinus brachyurus* (Fig. 1) was found trapped in a commercial tuna net in the "Tacche Bianche" locality in the channel between San Pietro Island and Sardinia, less than 500m from the northern coast of San Pietro Island (approx. 39°14′N, 8°31′E). The shark had probably been entangled for some days before being retrieved, as it already began to decompose.

The shark was initially identified by local fishermen as a "grigione" (big grey), a generic name usually adopted for carcharhinid sharks, particularly *Carcharhinus plumbeus* (Nardo, 1827), the most common carcharhinid in Sardinian waters (Storai *et al.*, 2006).

The identification of this specimen as *C. brachyurus* is based on several morphological features, observed from the photographs taken of the shark. These features match the diagnostic keys (Garrick, 1982; Compagno, 1984b), which allow definitely discriminate among the most two similar carcharhinid species *Carcharhinus obscurus* and *C. plumbeus* (Tab. 1). The specimen was recorded in the S.L.E.D. with the record code #2005 CB046.4. Conventionally, S.L.E.D. records are identified by a code of eleven alphanumeric characters, including: year of the signalling, first letter of the genus name and species name of the specimen, progressive number of the record, and a separate number (from 1 to 4) referring to one of the four areas into which Sardinian waters have been divided (Storai *et al.*, 2006). All records have been inserted in a multiple keywords database that will be available on the web site http: //www.dnaqua.it through restricted access granted by the webmaster. The stored data, periodically updated, will be thus available for both scientific and popular publications.

Fig. 1: Adult female** Carcharhinus brachyurus**, 253 cm TOT, caught in tuna net off San Pietro Island (south-western Sardinia, Italy, Mediterranean Sea) on June 19th, 2005 (S.L.E.D. record #2005CB046.4).
Sl. 1: Odrasla samica vrste** Carcharhinus brachyurus**, 253 cm TOT, ujeta v mrežo za lovljenje tunov 19. junija 2005 v bližini otoka San Pietro (jugozahodna Sardinija, Sredozemsko morje) (S.L.E.D. #2005CB 046.4).

Tab. 1: Matches of the specimen #2005CB046.4 with the main discrimination diagnostic features among *C. brachyurus, C. obscurus* ***and*** *C. plumbeus* ***(Compagno, 1984b).***
Tab. 1: Primerjave primerka #2005CB046.4 z glavnimi diagnostičnimi značilnostmi vrst *C. brachyurus, C. obscurus* ***in*** *C. plumbeus* ***(Compagno, 1984b).***

	#2005CB046.4	*C. brachyurus*	*C. obscurus*	*C. plumbeus*
upper dentition	narrow, mesial edge curved, distinct notch on distal edge	narrow, bent-cusped, serrated without cuspslets; crown feet with slightly coarser serrations but no cuspslets	erect, broad, triangular semioblique cusped, serrated without cuspslets; low erect to slightly oblique cups that smoothly merge into the crown feet	semierect, broad, triangular high cusped, serrated without cuspslets; semi-erect to slightly oblique cups that smoothly merge into the crown feet
snout shape	rounded, narrowly pointed	moderately long, rounded or narrowly pointed	short or moderately long, broadly rounded	short, broadly rounded or parabolic
interdorsal ridge	no interdorsal ridge relievable	no interdorsal ridge	low interdorsal ridge	narrow interdorsal ridge
first dorsal fin	small, falcate; origin slightly anterior to pectoral rear tip	small, falcate with short rear tip, no conspicuous markings; pointed or narrowly rounded apex; origin over or slightly anterior to pectoral rear tip	moderate-sized, semifalcate with short rear tip, no conspicuous markings; pointed or narrowly rounded apex; origin over or slightly anterior to pectoral rear tip	very large, semifalcate, no conspicuous markings; pointed or narrowly rounded apex; origin over or slightly anterior to pectoral fin insertion

RESULTS AND DISCUSSION

The specimen was 253 cm of total length and weighed more than 200 kg, and was distinguished from the two most similar carcharhinid species in the area, namely *Carcharhinus obscurus* (Lesueur, 1818) and *Carcharhinus plumbeus*. The upper dentition in our specimen is relatively narrow (Fig. 2), and not as broad as in *C. obscurus* or *C. plumbeus*. The mesial edges of the upper teeth in our specimen are pronouncedly curved, whereas the mesial edges of the upper teeth in both *C. obscurus* and *C. plumbeus* are straight, or nearly so, and a distinct notch is observed on the distal edges of the teeth in our specimen, whereas this notch is indistinct, or absent, in the distal edges of the upper teeth of *C. obscurus* and *C. plumbeus*.

The shape of the snout in our specimen is long and narrowly pointed (Fig. 3), as in *Carcharhinus brachyurus*, whereas the snouts of *C. obscurus* and *C. plumbeus* are shorter and more broadly rounded. The shape and size of the first dorsal fins of *C. brachyurus* and *C. obscurus* are similar; however, *C. plumbeus* has a characteristically high, triangular first dorsal fin, which is not the case in our specimen (Fig. 4). The shark specimen that we are reporting on has dentition, snout, and fin morphology that matches that of *C. brachyurus*. The dentition and shape of the snout of our specimen does not conform to the descriptions of *C. obscurus* or *C. plumbeus*, and the first dorsal fin shape of our specimen is different to the one observed in *C. plumbeus* (Bass *et al.*, 1973; Garrick, 1982; Compagno, 1984b, 1988).

Fig. 2: Detail of the upper jaw teeth of the specimen identified as *C. brachyurus***.**
Sl. 2: Detajl zob v zgornji čeljusti primerka, identificiranega kot *C. brachyurus***.**

Fig. 3: Detail of the head of the specimen identified as** C. brachyurus**, showing its mouth and snout.
Sl. 3: Detajl glave (čeljusti in gobca) primerka, identificiranega kot** C. brachyurus**.

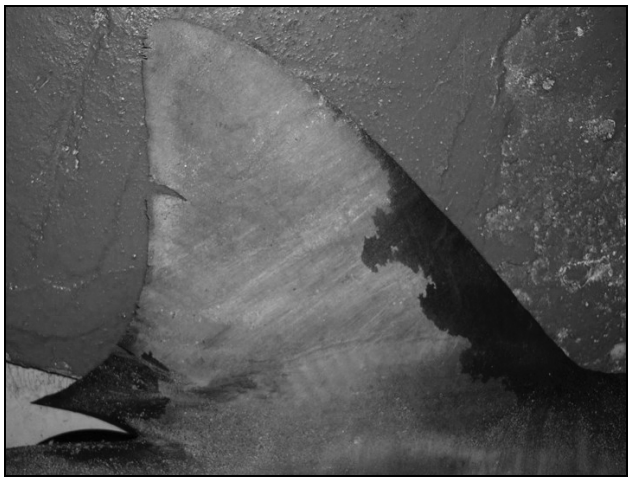

Fig. 4: Detail of the first dorsal fin of the specimen identified as** C. brachyurus**.
Sl. 4: Detajl prve hrbtne plavuti primerka, identificiranega kot** C. brachyurus**.

The following morphometric measurements (Tab.2) were collected as per Compagno (1984a) by the fishermen catching the shark: 253 cm Total Length (TOT), 182 cm (71.9% TOT) Precaudal Length (PRC), 131 cm (51.8% TOT) Snout-Vent Length (SVL), 33 cm (13.0% TOT) Preorbital Length (POB), and 29 cm (11.5% TOT) First Dorsal Height (D1H). Due to the logistic difficulties, it was not possible to make observations on the stomach contents, nor the reproductive tract, and no biopsy samples were taken.

Tab. 2: Synthesis of the available measurements of the specimen #2005CB046.4 caught off San Pietro Island (southwestern Sardinia, Italy, Mediterranean Sea) in June 2005.
Legend: TOT – total length; PRC – precaudal length; SVL – snout-vent length; POB – preorbital length; D1H – first dorsal height.
Tab. 2: Sinteza razpoložljivih dimenzij primerka #2005CB046.4, ujetega junija 2005 v bližini otoka San Pietro (jugozahodna Sardinija, Italija, Sredozemsko morje).
Legenda: TOT – celotna iztegnjena dolžina; PRC – predrepna dolžina; SVL – dolžina od konice gobca do trebušne plavuti; POB – dolžina od konice gobca do oči; D1H – višina prve hrbtne plavuti.

	TOT	PRC	SVL	POB	D1H
cm	253	182	131	33	29
% TOT	100	71.9	51.0	13.0	11.5

According to the literature available for *C. brachyurus* (Garrick, 1982; Vacchi *et al.*, 1996; Morey & Massuti, 2003; Zava *et al.*, 2006), the specimen was probably sexually mature, as sexual maturity for this species is usually reached at approximately 200–220 cm TOT (Compagno *et al.*, 2005; Serena 2005), although a recent record from the southern Tyrrhenian Sea (Zava *et al.*, 2006) reports on a mature male specimen at only 164 cm TOT.

This record of *C. brachyurus* from Sardinia confirms a geographical continuum in the distribution of *C. brachyurus* throughout the western Mediterranean Sea. *C. brachyurus* ranges from the Balearic Islands to the Algerian coast in the Mediterranean Sea. In our opinion, a reproductively viable population of *C. brachyurus* exists in the Mediterranean Sea.

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PRVI PODATEK O POJAVLJANJU VRSTE *CARCHARHINUS BRACHYURUS* (GUNTHER, 1870) (CHONDRICHTHYES; CARCHARHINIDAE) V VODAH SARDINIJE (SREDNJE SREDOZEMLJE)

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POVZETEK

Avtorji pričujočega članka poročajo o prvem pojavljanju vrste Carcharhinus brachyurus *(Gunther, 1870) (Chondrichthyes; Carcharhinidae) v vodah Sardinije, in sicer na osnovi zapisa v Sardinski bazi podatkov za velike morske pse in skate (S.L.E.D.). Junija 2005 se je v mrežo za lovljenje tunov, postavljeno v bližini otoka San Pietro (jugozahodna Sardinija, Sredozemsko morje), ujela samica pravega morskega psa, ki je bila na osnovi fotografij njenega zobovja in nekaterih morfoloških značilnosti pozneje identificirana kot* C. brachyurus.

Ključne besede: *Carcharhinus brachyurus,* razširjenost, Sardinska baza podatkov za velike morske pse in skate (S.L.E.D.), Sredozemsko morje

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OCCURRENCE OF STRIPED DOLPHINS *(STENELLA COERULEOALBA)* IN THE GULF OF TRIESTE

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ABSTRACT

Although the striped dolphin (Stenella coeruleoalba) *is occasionally reported in the Gulf of Trieste, it is not considered a regular species in the northern Adriatic Sea. Between April and October 2007, 3 different individuals were observed in the Gulf of Trieste. All three individuals were sighted in the area between April and May 2007. One of them stranded alive and died shortly after a rehabilitation attempt, while one was re-sighted in October 2007. Photo-identification data enabled the authors to distinguish between the 3 individuals.*

Key words: *Stenella coeruleoalba*, striped dolphin, cetaceans, sightings, strandings, Adriatic Sea

PRESENZA DI STENELLA STRIATA (STENELLA COERULEOALBA) NEL GOLFO DI TRIESTE

SINTESI

Esemplari di Stenella Striata (Stenella coeruleoalba) *vengono occasionalmente avvistati nel Golfo di Trieste, ma la specie non viene considerata quale regolare nel Nord Adriatico. Fra aprile ed ottobre 2007, 3 individui differenti sono stati avvistati nell'area in questione. Le segnalazioni primaverili dei tre individui sono quasi contemporanee, nel periodo fra aprile e maggio 2007. Uno degli esemplari si è arenato vivo ed è morto subito dopo la tentata riabilitazione, un altro invece è stato visto per la prima volta ad aprile e riavvistato nel mese di ottobre 2007. La foto-identificazione ha permesso agli autori di identificare con certezza gli individui.*

Parole chiave: *Stenella coeruleoalba*, Stenella Striata, cetacei, avvistamenti, arenarsi, mare Adriatico

INTRODUCTION

The striped dolphin (*Stenella coeruleoalba*) is currently the most abundant cetacean species in the Mediterranean Sea (Reeves & Notarbartolo di Sciara, 2006). It has a worldwide distribution in tropical and temperate waters and shows preference for highly productive, pelagic waters beyond the continental shelf, although it is distributed in both inshore and offshore habitat within the Mediterranean (Gaspari *et al.*, 2007). Although the most abundant species in the region, the Mediterranean population is subject to many threats and its current IUCN status is "vulnerable" (Reeves & Notarbartolo di Sciara, 2006). This species has occasionally been observed in the northern Adriatic Sea, where the bottlenose dolphin *(Tursiops truncatus)* is the only regularly reported cetacean species at present time (Kryštufek & Lipej, 1993; Bearzi *et al.*, 1998, 2004).

This paper presents records on 3 individual striped dolphins occurring in the Gulf of Trieste.

The Gulf of Trieste (Fig. 1), the northernmost part of the Adriatic Sea, is a semi-enclosed and shallow area of about 600 km^2, characterized by high variations of salinity and water temperature, high riverine output, strong stratification, occasional oxygen depletion and occasional mucous aggregate phenomena (Lipej *et al.*, 2000). Human activities, such as urbanization, maritime transport, fishery, mariculture and tourism, are very intense.

A short review of the published work

The historical data regarding sightings, strandings and captures of cetaceans in the area indicate that the occurrence of the striped dolphin in the Gulf of Trieste is in fact occasional. Therefore, sightings and strandings of the striped dolphin in the area remain relatively rare. Table 1 summarizes the information on the records of striped dolphins in the Gulf of Trieste between 1990 and 2002.

Data in Table 1 mostly derive from three publications (Spoto & Lapini, 1995; Francese, 1997; Picciulin *et al.*, 2001). No other written reports on striped dolphins from this area have been published until this paper.

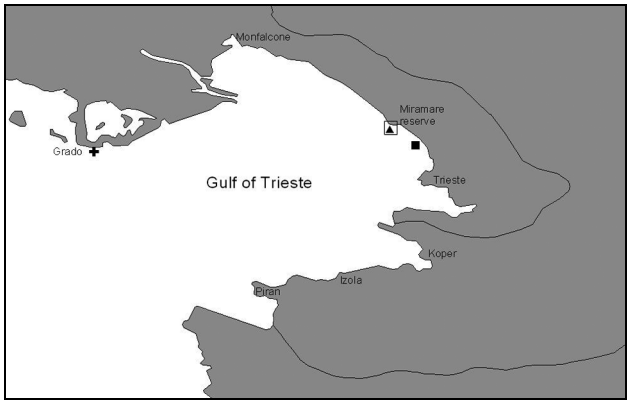

Fig. 1: Locations of sightings and strandings of striped** dolphins (Stenella coeruleoalba) **in the Gulf of Trieste in 2007. The triangle denotes several sightings (cases 1 and 4) in the Miramare Reserve. The cross indicates stranding of case 2, while the square represents the sighting of case 3.
Sl. 1: Lokacije navadnih progastih delfinov** (Stenella coeruleoalba), **opaženih in nasedlih v Tržaškem zalivu leta 2007. Trikotnik ponazarja več opažanj (primera 1 in 4) v rezervatu Miramare, križec nasedli primer 2, kvadrat pa opažanje primera 3.

Tab. 1: Sightings and strandings of the striped dolphin in the Gulf of Trieste recorded in the database of WWF – Miramare Natural Marine Reserve between 1990 and 2002.
Tab. 1: Navadni progasti delfini, opaženi in nasedli med letoma 1990 in 2002 v Tržaškem zalivu po podatkovni bazi WWF – rezervat Miramare.

Date	No. individuals	Location of sighting	Location of stranding
19/6/1990	1	Duino, Rilke, Sistiana	
6/10/1990	1	Miramare marine reserve	
11/10/1990	1	Trieste coastline (Barcola)	
12-16/11/1990	1	Miramare marine reserve	
15/4/1992	1		Fossalon di Grado (GO)
10/5/1992	1		Grado (GO)
10/6/1995	2	Barcola, Miramare	
1/12/1995	1		Grado (GO)
18/11/1996	1		Grado (GO)
11/5/1998	1	Port of S. Rocco (Muggia)	
20/5/1999	1	Canale navigabile (Trieste)	
21/07/2002	2	S. Croce (Trieste)	

As indicated in Table 1, the records of striped dolphins are not uniformly distributed in all years. Instead, 4 records were reported in 1990, 2 in 1992, 2 in 1995, 1 in 1996, 1 in 1998, 1 in 1999 and 1 in 2002. Out of 12 total recorded cases (not including the 4 cases reported in this paper) over 17 years, 4 were a result of an intervention of stranded animals. Others involved live animals, mostly reported by fishermen, tourists, locals, coast guard or officials carrying out surveillance in the Gulf of Trieste.

Sightings of striped dolphins have been reported from other parts of the northern Adriatic Sea, such as the area off the island of Lošinj in Croatia (Bearzi *et al.*, 1998) and around the island of Krk, Croatia (A. Wiemann, *pers. comm.*; T. Genov, *pers. observ.*).

MATERIALS AND METHODS

The methods in cases of sightings and particularly strandings of cetaceans are summarized in Francese *et al.* (1999). Sightings are recorded onto specifically designed sighting forms which include information on the species observed, the date and location of the sighting, group size, environmental conditions and possibly even animal characteristics, such as behaviour, size, age class, etc. Whenever possible, such data is coupled with photographic material for possible species and individual identification.

A special integrated contingency plan is designed for cases of strandings or animals in distress.

RESULTS

Case 1. On April 23, 2007, a dolphin sighting was reported to the Miramare staff by the coastguard of Trieste and the animal was later observed by scientists of Miramare (Fig. 2). The animal was probably an adult with a length of about 1.80–2 m. It was swimming slowly close to the buoy marking the limits of the Miramare Natural Marine Reserve, performing regular dives of relatively short duration. The animal was in apparently good physical condition and appeared to be chasing blue fish residing in the reserve. It appeared calm and even approached the boat. The Miramare staff, which was already involved in underwater acoustic work, attempted to record underwater vocalizations of the dolphin, however with no success.

A series of photographs of the animal's dorsal fin were taken for the purpose of photo-identification (Würsig & Jefferson, 1990), together with notes on the position and behaviour of the animal. The same individual was encountered in the Reserve on 5 consecutive days, performing leaps among other behaviours. Video footage was taken and archived.

Fig. 2: The first individual striped dolphin** (S. coeruleoalba) **observed in the Miramare Reserve in April 2007. (Photo: M. Tempesta)
Sl. 2: Prvi osebek progastega delfina** (S. coeruleoalba), **opažen aprila 2007 v rezervatu Miramare. (Foto: M. Tempesta)

Case 2. On May 15, 2007, the Grado coastguard informed the Miramare staff of a dolphin in apparent difficulty near the coast of Grado – Città Giardino. It later turned out that the animal was a male striped dolphin.

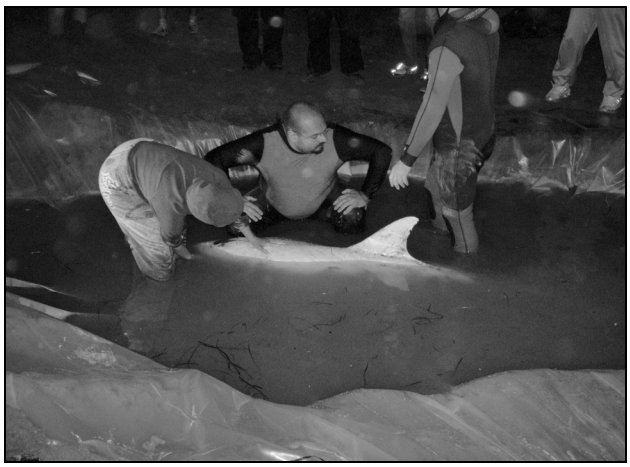

Fig. 3: The second individual striped dolphin** (S. coeruleoalba) **that stranded off Grado in May 2007. (Photo: M. Tempesta)
Sl. 3: Drugi osebek progastega delfina** (S. coeruleoalba), **ki je maja 2007 nasedel pri Gradežu. (Foto: M. Tempesta)

Tab. 2: Information on the stranded striped dolphin on May 15, 2007, Grado.
Tab. 2: Podatki o navadnem progastem delfinu, ki je 15. maja 2007 nasedel pri Gradežu.

Time frame	Sex	Weight	Body measurements	
Sighted: May 15, 2007, 17:00 hrs Died: May 16, 2007, 02:00 hrs Necropsy: May 16, 2007, 13:00 hrs	Male	103.2 kg	Total length: 215 cm Rostrum length: 10 cm Pectoral fin – rostrum: 92 cm Pectoral fin – tail notch: 93 cm Dorsal fin height: 22 cm	Genital slit – anal slit: 32 cm Pectoral fin length: 52 cm Pectoral fin width: 30 cm

Despite the attempts to prevent the animal from stranding, it ended up in shallow water. It was weak and clearly not able to return to open sea. In order to keep the animal afloat and in the sea despite the increasingly low tide, a hole was dug under the animal and filled with sea water (Fig. 3). Vaseline was applied to the animal's skin in order to prevent it from drying out. The animal was then transported to the facility of the civil protection service in Grado, where it was placed in a small tank. Once the animal arrived, it started to show signs of fatigue and difficulty in staying afloat. The animal was therefore assisted in keeping afloat with a life-jacket, in order to enable breathing and preventing the animal from turning to its side. Despite these efforts, the dolphin died shortly afterwards.

The animal bore several external parasites (copepods of the genus *Penella)* and numerous subcutaneous cysts. The necropsy has shown a high prevalence of internal parasites in the area of abdominal muscles (presumably a cestode species *Phyllobothrium delphini)* and in the digestive system (presumably a nematode *Anisakis* sp.). Samples of muscle tissue, adipose tissue, liver, spleen, kidney, cerebellum were taken for the analysis of pollutants concentrations, biomarkers, etc.

Photographs of dorsal fin were taken for the purpose of photo-identification. The comparison with photos of the live striped dolphin sighted at Miramare (Case 1, see above) revealed that it was not the same individual.

Case 3. On May 21, 2007, the Morigenos Marine Mammal Research and Conservation Society received an e-mail sighting report by a Slovenian sailing coach. The sighting took place on May 19, 2007 at 14:00 between Trieste and the Miramare Reserve, relatively close to coast (likely less than 2 km), near a small sailing regatta. The animal swam alongside the reporter's inflatable boat for about 10 minutes and was also engaged in bowriding. The e-mail message included a photo (Fig. 4) taken by the person who reported the sighting. Morigenos researchers immediately discovered that the dolphin belonged to the species of striped dolphin and informed the Miramare staff about the sighting. The relatively good photo allowed photo-identification comparisons to be made and it was discovered that the animal was in fact a 3rd individual. Video footage was also acquired, which further corroborated the information provided.

Fig. 4: The third individual striped dolphin** (S. coeruleoalba), **observed in May 2007 between Trieste and the Miramare Reserve. (Photo: D. Poljšak)
Sl. 4: Tretji osebek progastega delfina** (S. coeruleoalba), **opažen maja 2007 med Trstom in rezervatom Miramare. (Foto: D. Poljšak)

Case 4. On October 5, 2007, another striped dolphin was observed and photographed in the Miramare Reserve (Fig. 5). Photo-identification comparisons revealed that the animal was the same individual sighted alive in April 2007 in the Miramare Reserve (Case 1, see above). The dolphin either remained in the area or returned there. At the time of the submission of this manuscript (October 23 2007), the animal was still in the area.

DISCUSSION AND CONCLUSIONS

The presence of the striped dolphin in the Gulf of Trieste is considered a rather unusual event and such cases usually involve single individuals, often in distress. The more or less contemporary presence of at least 3 individual striped dolphins in the area is an interesting phenomenon. Two of them were apparently in good health. One of the animals was re-sighted in the very same area about 5 months later. Unfortunately, the movement patterns of this animal during these months are unknown.

Fig. 5: The first individual striped dolphin *(S. coeruleoalba),* ***observed again in the Miramare Reserve in October 2007. (Photo: M. Tempesta)***
Sl. 5: Prvi osebek progastega delfina *(S. coeruleoalba),* ***znova opažen oktobra 2007 v rezervatu Miramare. (Foto: M. Tempesta)***

Apart from the bottlenose dolphin *(Tursiops truncatus),* which is the only regularly sighted cetacean in the northern Adriatic, some other species of cetaceans might be considered occasional in the region. These include the fin whale *(Balaenoptera physalus)* (Lipej *et al.*, 2004), Risso's dolphin *(Grampus griseus)* (Zucca *et al.*, 2005) and the striped dolphin (this paper). The once common short-beaked common dolphin *(Delphinus delphis)* is considered regionally rare or even extinct in this region (Bearzi *et al.*, 2004).

Reports on striped dolphins in the northern Adriatic Sea may simply reflect the occasional occurrence of stray individuals, but the fact that such observations have only occurred in recent times might be indicative of a progressive extension of the species' range, as has been reported for other Mediterranean areas (Notarbartolo di Sciara & Demma cited in Bearzi *et al.*, 1998). However, the increased interest in cetaceans in the last 10–15 years may also contribute to a higher number of reports and therefore chances of documenting the occurrence of these animals (Bearzi *et al.*, 1998). The true reasons yet remain unknown. Future research should shed more light onto the status of this species in the northern Adriatic.

Cooperation and information exchange between research groups is fundamental for continuous and effective monitoring of cetaceans in an area like the Gulf of Trieste. Furthermore, acquiring information often depends on the awareness and good will of opportunistic observers that send information to the relevant bodies. When coupled with photographic and/or video material, such information can be of high value. Even if the data are not collected by trained personnel and should therefore not always be considered reliable, the additional photo/video material adds weight to such information. In cases of animals in difficulty (or even dead stranded animals), the integrated and coordinated response actions are of great importance, both to ensure the animal's welfare and to collect valuable data.

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POJAVLJANJE NAVADNIH PROGASTIH DELFINOV *(STENELLA COERULEOALBA)* V TRŽAŠKEM ZALIVU

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POVZETEK

Navadni progasti delfin (Stenella coeruleoalba) *je danes najbolj pogosta oz. številna vrsta kitov v Sredozemlju. V severnem Jadranskem morju, kjer velika pliskavka* (Tursiops truncatus) *velja za edino stalno prisotno vrsto, so opažanja navadnega progastega delfina občasna. Med aprilom in oktobrom 2007 so bili v Tržaškem zalivu zabeleženi 3 različni posamezni navadni progasti delfini. Prvi je bil opažen v aprilu 2007 v rezervatu Miramare in ostal tam skoraj en teden. Isti primerek je bil vnovič večkrat opažen oktobra 2007. Drugi je živ nasedel na obali Gradeža in kmalu poginil, kljub poskusom rehabilitacije. Tretji je bil opažen maja 2007, med rezervatom Miramare in Trstom. S foto-identifikacijo posameznih osebkov smo lahko ugotovili, da so se skoraj ob istem času v Tržaškem zalivu zadrževali vsaj trije osebki. Navadni progasti delfini niso obravnavani kot stalni del severnojadranske favne, čeprav se lahko njihova opažanja na tem območju označijo kot občasna, a ne redka. Prihodnje raziskave bi morale zagotoviti več informacij o statusu te vrste v severnem Jadranskem morju.*

Ključne besede: *Stenella coeruleoalba*, navadni progasti delfin, kiti, opažanja, mrtvi delfini, Jadransko morje

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INLAND OBSERVATIONS OF COMMON BOTTLENOSE DOLPHINS *TURSIOPS TRUNCATUS* (MONTAGU, 1821) IN THE DELTA OF THE BOJANA/BUNA RIVER, ALBANIA AND MONTENEGRO

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ABSTRACT

During the waterbird surveys conducted between April 2003 and January 2004, common bottlenose dolphins Tursiops truncatus *were sighted* c. *10 km upstream in the lower Bojana/Buna River along the east coast of the Adriatic Sea. With a maximum group size of 6 individuals, the dolphins were observed upstream in the Bojana/Buna River only during the summer, which corresponds to the period of low water level of the river. The Bojana/Buna delta, which is largely unobstructed by embankments and urban development, is one of the few areas in the Mediterranean region where the species still occurs within a narrow riverine system. The inshore habits of dolphins in the delta are probably linked to the low level of human disturbances along the borderline between Albania and the former Yugoslavia till the end of the last Balkan War.*

Key words: common bottlenose dolphin, *Tursiops truncatus*, Bojana/Buna River, Albania, Montenegro, Adriatic Sea

OSSERVAZIONI INTERNE DI TURSIOPI *TURSIOPS TRUNCATUS* (MONTAGU, 1821) NEL DELTA DEL FIUME BOJANA/BUNA, ALBANIA E MONTENEGRO

SINTESI

Durante una ricerca sugli uccelli d'acqua, tra aprile 2003 e gennaio 2004, gli autori hanno avvistato i tursiopi, Tursiops truncatus*, risalendo per 10 km il fiume Bojana/Buna (Adriatico orientale). I tursiopi sono stati avvistati esclusivamente nel periodo estivo, quando la portata e il livello dell'acqua sono minimi, con un massimo di 6 individui nel gruppo. Il delta del fiume Bojana/Buna è prevalentemente non ostruito da argini e sviluppo urbano, ed è pertanto una delle rare aree mediterranee dove i tursiopi vengono avvistati in uno stretto sistema fluviale. Le ragioni di questa presenza vanno probabilmente ricercate nel basso influsso umano nell'area di frontiera tra l'Albania e la ex-Yugoslavia, fino al termine dell'ultima guerra dei Balcani.*

Parole chiave: tursiope, *Tursiops truncatus*, fiume Bojana/Buna, Albania, Montenegro, mare Adriatico

INTRODUCTION

Most information on free-ranging cetaceans from the Adriatic Sea derives from stranding reports and opportunistic sightings (*cf.* reviews by Marchessaux, 1980; Bearzi *et al.*, 2004; Reeves & Notarbartolo di Sciara, 2006). While extensive surveys have been conducted in the northern part of the Adriatic Sea since the 1980s (Notarbartolo di Sciara *et al.*, 1993; Bearzi & Notarbartolo di Sciara, 1995), the occurrence of cetaceans – *i.e.* sperm whale *Physeter macrocephalus*, Cuvier's beaked whale *Ziphius cavirostris* and common bottlenose dolphin *Tursiops truncatus* (the later hereafter 'bottlenose dolphin') - in the coastal waters of Albania and Montenegro is known from occasionally stranded specimens only (Beaubrun, 1995; Reeves & Notarbartolo di Sciara, 2006; D. Ulqini, *pers. comm.*). In the northern Adriatic Sea, population numbers of bottlenose dolphins have declined by at least 50% during the 20th century, most probably as a result of historical culling campaigns, habitat destruction, overfishing and human disturbances (Bearzi *et al.*, 2004). In contrast to the northern part of the Adriatic Sea, very few data on the current distribution and status of the species in the southern Adriatic are available (Notarbartolo di Sciara *et al.*, 1993; Hussenot & Robineau, 1994; Bearzi *et al.*, 2004; Reeves & Notarbartolo di Sciara, 2006). Here we document the presence of bottlenose dolphins in the delta of the Bojana/Buna River along the borderline between Albania and the former Yugoslavia based on direct but opportunistic observations and accidental reports by the locals.

MATERIAL AND METHODS

Between April 2003 and January 2004, we performed waterbird surveys throughout the *c.* 250 km^2 floodplains of the 42 km long Bojana/Buna River from Shkodra (Albania), downstream to the head of the delta at the Adriatic coast (Stumberger *et al.*, 2005). A total of 147 field days were spent in the area between April-July 2003, October-November 2003, and in January 2004. About 17 km of the river's banks upstream to the village of Sveti Đorde and all coastal habitats and inshore waters of the delta between Ulcinj/Ulqini in Montenegro and Baks-Rrjolli in Albania (34 km) were investigated during 134 hrs of transect counting along shoreline (Tab. 1).

RESULTS AND DISCUSSION

Bottlenose dolphins were encountered on four occasions, totalling 3 sightings/100 h (Fig. 1). On June 12th, a single dolphin (probably a mature male according to body size) was observed in the eastern branch of the delta between Ada Island and the Albanian river bank, 1.7 km upstream the river mouth (Fig. 2). On July 7th, six bottlenose dolphins were present in the Bojana/Buna River close to Paratuk, a small island off the Montenegran river bank 9.5 km upstream the river's mouth. In addition, two (sub)groups of 3 and 5 dolphins, the latter including a calf, were seen on November 3rd simultaneously at sea approximately 0.5-1 km apart and 300-600 m from shoreline close to the mouth of the northern branch of the river off Ada Island. The only other cetaceans we have sighted in the area were two striped dolphins *Stenella coeruleoalba* in the sea off the old town (Kajala) of Ulcinj/Ulqini in April 2003.

Tab. 1: Observation effort (transect counts), the entire number of sightings/month, with the number of sightings reported by local people in parentheses, and maximum group size of common bottlenose dolphins** Tursiops truncatus **in the Bojana/Buna delta, April 2003-January 2004.
Tab. 1: Opazovanja (štetja po transektih), skupno število opazovanj/mesec (s številom opazovanj s strani domačinov v oklepaju) in največja skupina velikih pliskavk** Tursiops truncatus **v delti Bojane/Bune v obdobju med april 2003 in januarjem 2004.

Month	Observation time (hrs)	No. sightings	Maximum group size
April 03	54.8		
May	2.7		
June	8.8	3(2)	2
July	0.8	2(1)	6
August	-		
September	-		
October	-		
November	47.5	3(1)	5
December	-		
January 04	20.3		

Further sightings of single and small groups of dolphins in the Bojana/Buna River were reported by the locals close to the villages of Reci (Albania), Sveti Đorde (Montenegro) and Derragjati (Albania), 7-35 km inland along the river's course, and a carcass of a newborn dolphin was reported from Franz-Joseph Island in the river mouth in mid-July 2003 (Fig. 1). Considering that all observers were scientifically untrained, in all latter cases a definite identification of the species was not possible. In addition, local commercial fishermen who operate in offshore waters frequently reported dolphin sightings during their operations, while in October 2005 a carcass of *T. truncatus*, which is now preserved in the National Museum in Tirana, was found at Shengjin, *c.* 20 km south of the delta (D. Ulqini, *pers. comm.*).

While we saw the species *c.* 10 km upstream in the Bojana/Buna River, bottlenose dolphins may occur regularly further inland according to the anecdotal reports by the locals mentioned above. The river bed, where we sighted the bottlenose dolphins, is 350 and 420 m wide, while maximum water depth is 9 m near

Paratuk according to sonar measurements by G. Resulbegović *(pers. comm.)*. The largest schools of 5 and 6 individuals were seen in July and November. Although our survey effort/month along the riverbanks and coastline was much greater in April-May and during winter (123 hrs or 92% of total observation time), we saw dolphins upstream in the lower Bojana/Buna River only in June and July (Tab. 1). This period coincides with the lower water level of the river during the summer (Schneider-Jacoby *et al.*, 2006), when fish may be more abundant or, in view of the lower water depth of the river, better available for dolphins.

Apart of a highly philopatric population in the Amvrakikos Gulf in the Ionian Sea, Greece (Bearzi *et al.*, 2007), very few inland sightings of bottlenose dolphins are known from the Mediterranean and Black Sea regions (Reeves & Notarbartolo di Sciara, 2006). While many estuarine and riverine populations are reported elsewhere in the world (Odell & Asper, 1990; Ingram, 2000), the Bojana/Buna River appears to be one of the few areas in the Mediterranean where bottlenose dolphins still occur within a narrow riverine system. Local fishermen in Albania have told us that in "former times" dolphins were sometimes seen even in Shkodra at the southeastern end of Lake Skutari.

In contrast to other estuarine habitats and river deltas

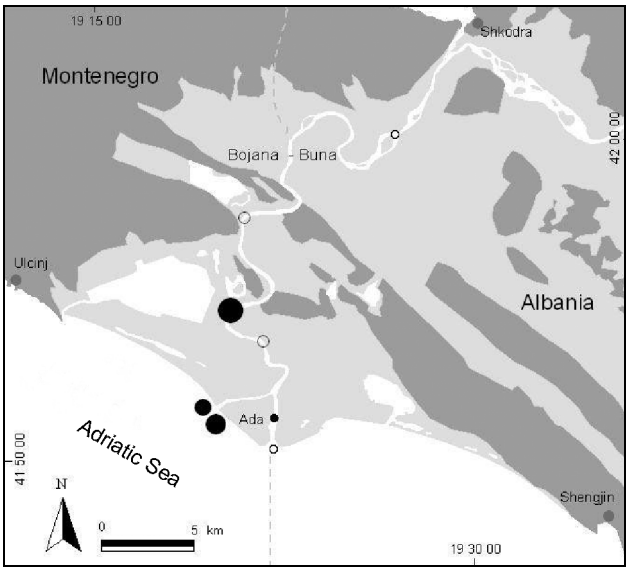

Fig. 1: Sightings of common bottlenose dolphins *Tursiops truncatus* ***in the Bojana/Buna delta in 2003. Full circles: sightings by authors; open circles: sightings reported by the locals. Size of symbols indicates group size (min: 1, max: 6 individuals).***
Sl. 1: Opazovanja velikih pliskavk *Tursiops truncatus* ***v delti Bojane/Bune v letu 2003. Polni krožci: opazovanja s strani avtorjev; prazni krožci: opazovanja s strani domačinov. Velikost simbolov ponazarja velikost skupine velikih pliskavk (min: 1, max: 6 osebkov).***

Fig. 2: Eastern branch of the Bojana/Buna delta on the borderline between Albania and Montenegro; location of dolphin sighting on June 12th, 2003. (Photo: P. Sackl).
Sl. 2: Vzhodni rokav delte Bojane/Bune na meji med Albanijo in Črno goro; lokacija opazovanja velike pliskavke dne 12. junija 2003. (Foto: P. Sackl).

of the Mediterranean region, the lower Bojana/Buna river is largely unobstructed by embankments and urban development (Schneider-Jacoby *et al.*, 2006). According to the heavy persecution of cetaceans by fishermen throughout the Adriatic Sea till the 1990s (Bearzi *et al.*, 2004), the presence of the species may be further linked to the low level of human disturbances in the area. Till the end of the last Balkan War in 2001, access to the lower Bojana/Buna River along the borderline between Albania and the former Yugoslavia was largely restricted. Since our survey in 2003/04, disturbances have increased and areas along borderline have recently been used by net and, on the Albanian side, by dynamite fishing, although boating and hunting is still officially prohibited. Besides the formal establishment of the proposed transboundary Bojana/Buna Delta Marine Park (Schneider-Jacoby *et al.*, 2006), a strict control of human activities in the area is needed. Their inshore habits make dolphins in the Bojana/Buna River particularly vulnerable to anthropogenic threats, highlighting the need for enforcing appropriate science-based management measures.

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OPAZOVANJA VELIKE PLISKAVKE *TURSIOPS TRUNCATUS* (MONTAGU, 1821) V DELTI BOJANE/BUNE, ALBANIJA IN ČRNA GORA

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POVZETEK

Med aprilom 2003 in januarjem 2004 smo ob popisih vodnih ptic opazovali velike pliskavke Tursiops truncatus *kakih 10 kilometrov po reki Bojani/Buni navzgor (vzhodni Jadran). Z največ 6 pliskavkami v skupini smo te videvali izključno poleti, ko sta bila pretok in gladina reke majhna. Rečna delta Bojane/Bune je pretežno neuravnana – v veliki meri jo je obšla tudi urbanizacija – in je eno redkih območij v Sredozemlju, kjer se pliskavka pojavlja v reki. Verjetni vzrok pojavljanja v rečni delti je majhen človekov vpliv vzdolž meje med Albanijo in nekdanjo Jugoslavijo vse do konca zadnje balkanske vojne.*

Ključne besede: velika pliskavka, *Tursiops truncatus*, reka Bojana/Buna, Albanija, Črna gora, Jadransko morje

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OVERVIEW OF EUTROPHICATION-RELATED EVENTS AND OTHER IRREGULAR EPISODES IN SLOVENIAN SEA (GULF OF TRIESTE, ADRIATIC SEA)

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ABSTRACT

Eutrophication is one of the important drivers of marine ecosystems degradation and is a particularly evident problem near the centre of human population. Although advances have been made during the past 30 years, eutrophication remains one of the primary problems affecting coastal marine ecosystems and semi-enclosed seas. An overview of eutrophication and its consequences in the Slovenian sea is presented with a focus on the pelagic domain, communities of the coastal ecosystem in particular on bacterio- and phytoplankton abundance, production, frequency of blooms and dominant organisms, occurrence of harmful toxic algal species, swarming of gelatinous zooplankton, the mucilage phenomenon and on hypoxia/anoxia events in the bottom layers.

Key words: eutrophication, nutrients, plankton, blooms, anoxia, mucus aggregates, Gulf of Trieste

VALUTAZIONE SU EVENTI LEGATI ALL'EUTROFIZZAZIONE E ALTRI EPISODI SPORADICI IN MARE SLOVENO (GOLFO DI TRIESTE, MARE ADRIATICO)

SINTESI

L'eutrofizzazione è uno dei vettori più importanti della degradazione degli ecosistemi marini ed è un problema particolarmente evidente in prossimità dei centri abitati. Benchè negli ultimi trent'anni la ricerca abbia fatto progressi, l'eutrofizzazione rimane uno dei problemi primari che affliggono gli ecosistemi marini costieri e i mari semichiusi. L'articolo presenta una valutazione dell'eutrofizzazione e delle conseguenze in mare sloveno, incentrata soprattutto sul dominio pelagico. Vengono trattate le comunità degli ecosistemi costieri, in particolare l'abbondanza di batterio- e fitoplancton, la produzione primaria, la frequenza delle fioriture, la presenza di organismi dominanti, specie algali tossiche e zooplancton gelatinoso, i fenomeni mucillaginosi e l'ipossia/anossia degli strati di fondo.

Parole chiave: eutrofizzazione, nutrienti, plancton, fioriture, aggregati mucillaginosi, Golfo di Trieste

AREA DESCRIPTION

The semi enclosed Gulf of Trieste is the northernmost part of the Mediterranean Sea opened to the rest of the northern Adriatic along its western side (Fig. 1). The surface area of the Gulf is about 600 km^2, while its volume is estimated at 9.5 km^3. With few exceptions, the water depth does not exceed 25 m, and only 10% of the Gulf is shallower than 10 m (Malej & Malačič, 1995). Oceanographic properties of the Gulf were described recently by Malačič & Petelin (2001); they are strongly affected by water mass exchange from the southern Adriatic, river inflow and meteorological conditions. It is the river Soča (Isonzo) that exerts the greatest impact on the Gulf's dynamics. Except during the summer months, a plume of freshwater from the Soča (Isonzo) river is always present in the surface layer of the Gulf, and freshwater may spread on the surface as far down as to the middle of the Gulf (Malej *et al.,* 1995). Oligotrophic, southern Adriatic bottom water enters the Gulf at the southern side and flows out after mixing with the upper waters. Circulation of deeper water is cyclonic and can be opposite to that in the upper layer (Malačič & Petelin, 2001). Discharge by other rivers along the eastern and southern coastline is minor (about 10%; Olivotti *et al.,* 1986a; Malačič *et al.,* 2006), and might have an impact on the ecology of the inner shallow bays.

Mean monthly temperatures in the last ten years vary from 9.2 to 25.0 ºC, with salinity fluctuating from 32.8 to 36.7, showing quick changes in the upper layers of the water column. Statistical analysis of the inter-annual variations of mean seasonal temperatures over the past ten years show an increase in temperature between 0.12 and 0.23 ºC per year. In addition, an inter-annual trend for increasing salinity in the surface layer of the Gulf was observed (Malačič *et al.,* 2006). Strong variations of sea water temperature, stratification of the water column and total irradiance during the year determine the pronounced seasonal cycles in the Gulf of Trieste (Malačič & Petelin, 2001).

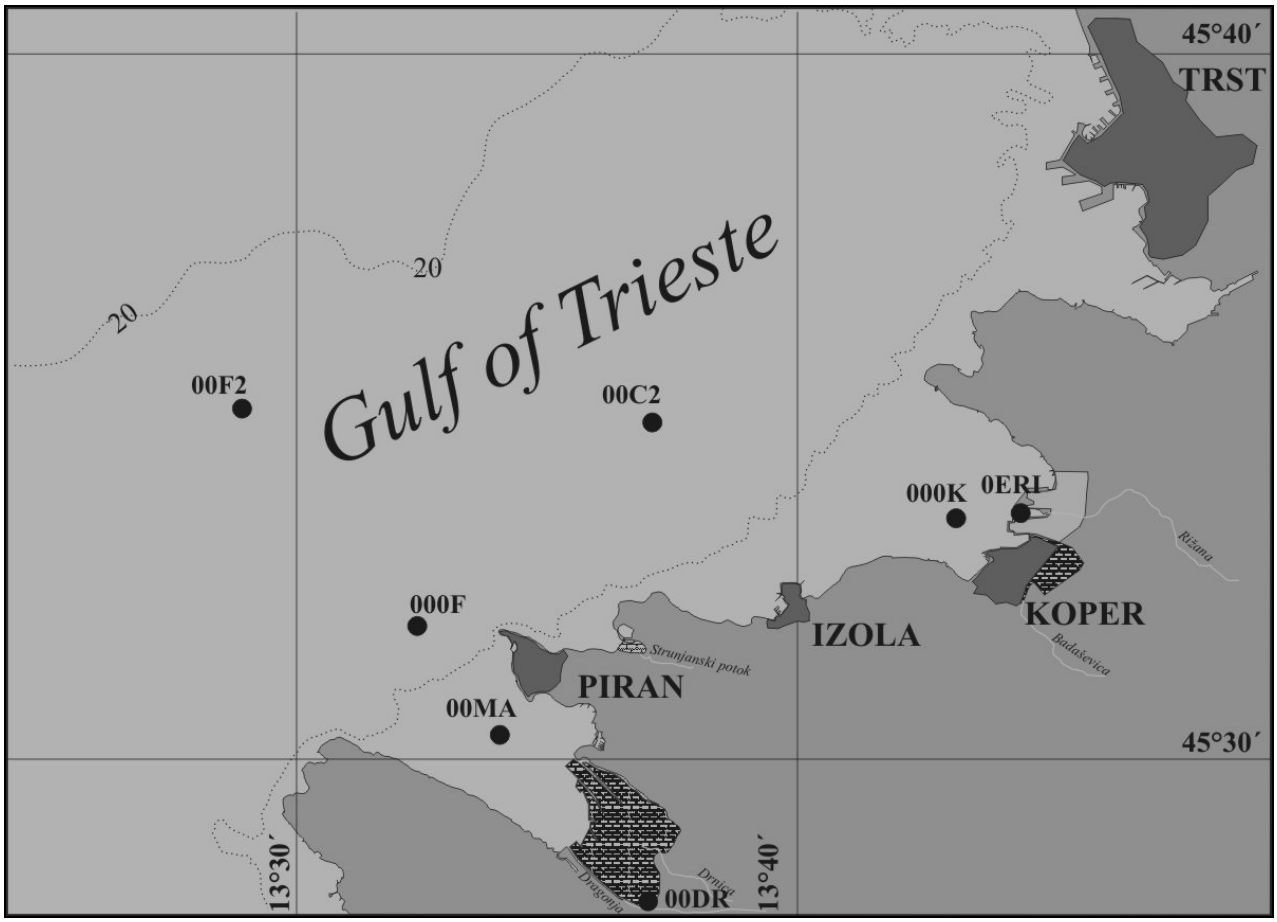

Fig. 1: Location of sampling stations for the purpose of eutrophication monitoring in the Slovenian sea (Gulf of Trieste).
Sl. 1: Prikaz merilnih mest evtrofikacijskega monitoringa v slovenskem morju (Tržaški zaliv).

LAND-BASED SOURCES OF POLLUTION AND TROPHIC STATUS OF MARINE ENVIRONMENT

Impact of anthropogenic nutrient inputs on the quality of the coastal waters has been studied in the Gulf of Trieste since the early seventies (Štirn, 1968, 1971a, 1971b; Štirn *et al.,* 1974; Olivotti *et al.,* 1986a, 1986b; Štirn, 1993). The main sources of potential pollutants, including those from fresh water inflows and sewage discharges into the Gulf of Trieste, were presented by Olivotti *et al.* (1986a, 1986b), whereas those directly affecting the Bay of Koper were studied by Turk & Potočnik (2001). According to the data and criteria of the severity of the effects on the marine environment, the estuaries of the Rižana and Badaševica rivers are the main pollution hot spots along the Slovenian coast (Turk & Potočnik, 2001). The rivers receive mainly untreated or primarily treated urban and industrial wastewater from the town of Koper and inland agglomerations along the river banks. The input of some pollutants into the coastal sea is estimated annually on the basis of the average flow rates and average concentrations of pollutants in the river estuaries and at the outlets of wastewater treatment plants (WWTP) in Koper and Piran (Tušnik *et al.*, 1989; Turk *et al.,* yearly reports 2000–2006). The gross fluxes for suspended solids, nitrogen and phosphorous attained the 2340 t, 935 t and 45 t per year, respectively (Tab. 1) for the 2000–2006 period. The evaluation inputs do not differ if compared with previous years (Tušnik *et al.*, 1989). Statistical evaluation of maximal values of nutrient concentrations from seasonal measurements in river estuaries along the Slovenian coast showed an increase in total nitrogen and decrease in total phosphorous for the 1988–2006 period (Fig. 2). The quantities of estimated inputs along the Slovenian coast are minimal in comparison with other areas of the Northern Adriatic (Tušnik *et al.*, 1989; Pagnotta *et al.*, 2000). However, high inputs of nitrogen and phosphorous influence the quality of the estuary in the inner part of the Bay of Koper.

The impact of organic and bacterial polluted wastewater discharged into the stratified estuary of the Rižana River and the inner part of the shallow Bay of Koper was studied only in the late 80's (Faganeli & Turk, 1989; Turk & Faganeli, 1990). The results of seasonal measurements of chemical and bacterial parameters showed that dissolved organic matter is mainly controlled by bacteria and related to the water temperature and river discharge. Dissolved organic nitrogen and dissolved organic phosphorous are mineralized and ammonia is nitrified, while dissolved organic carbon is controlled by mineralization and chemical precipitation. During the summer, when the estuary is characterized with low flow rate and high water temperature, oxygen and nitrate depletion prevail, showing dominance of denitrification processes. The application of such biogeochemical studies is important for prediction of anthropogenic impacts on small estuaries and inner part of the bays. The high concentrations of faecal coliforms, as the main pollution indicators, were found in the area close to the main sewage outfall. The concentration of faecal bacteria declined towards the middle of the Bay of Koper, and could be detected approximately 400–800 m from the pollution source (Lenarčič, 1980; Turk *et al.,* 1982; Turk, 1987).

In the seventies and eighties, several studies examined the impact of untreated sewage on ecosystems in experimental lagoons (Malej *et al.*, 1979; Vukovič, 1994), and the impact of the underwater sewage outfall on surroundings in the Bay of Piran (Avčin *et al.,* 1979; Malej *et al.,* 1979, 1980a). In sewage pollution experiments in the enclosed lagoon system, the phytoplankton biomass was significantly reduced and phytoplankton community changed (Fanuko, 1984). In contrast, a high

Tab. 1: Gross input of total phosphorous (Tot P), total nitrogen (Tot N) and total suspended solids (TSS) in the Slovenian coastal sea in the 1989–2006 period. Estimates are based on yearly average flow rates and on nutrient/TSS concentrations in the riverine inflows and in the effluents of wastewater treatment plants (WWTP).
Tab. 1: Celoten vnos celokupnega fosforja (Tot P), celokupnega dušika (Tot N) in suspendirane snovi (TSS) v slovensko obalno morje v obdobju 1989–2006. Ocena vnosa je narejena na osnovi povprečnih letnih pretokov in koncentracij hranil/TSS v rečnih pritokih in odplakah čistilnih naprav (WWTP).

Inflows / effluents	Flow rate (10^6 m^3 yr^{-1})	Tot P (t yr^{-1})	Tot N (t yr^{-1})	TSS (t yr^{-1})
Rižana	110	4	464	1136
Badaševica	8.5	1	63	45
Drnica	8.9	2	48	52
Dragonja	23	1	89	98
WWTP Koper	4.3	22	146	581
WWTP Piran	3.4	15	125	428
Total		**45**	**935**	**2340**

concentration of nutrients provoked a proliferation of the nitrophilic benthic macroalgae, mainly *Ulva rigida* (Vukovič, 1994). More recently, yearly studies examined the distribution of wastewater in the water column from diffusers of the Piran sewage outfall (Malačič & Vukovič, 1997; Malačič *et al.*, 2000). The initial spread of sewage from diffusers in the Bay of Piran was studied with numerical modelling (Malačič, 2001), whereas the impact of nutrients on selected biological parameters has been presented by Mozetič *et al.* (1999) and Flander Putrle & Malej (2003). The influence of anthropogenic emissions was also recorded by the measurements of atmospheric depositions during the 10 June – 10 September 1993 period (Malej *et al.*, 1997). Rainfall events delivered considerable amount of nutrients (127 t of nitrogen and 9.5 t of phosphorous), which enhanced primary production and phytoplankton biomass in mesocosm experiment as well as in field measurements, and were connected with a shift in community structure of phytoplankton (Malej *et al.*, 1997).

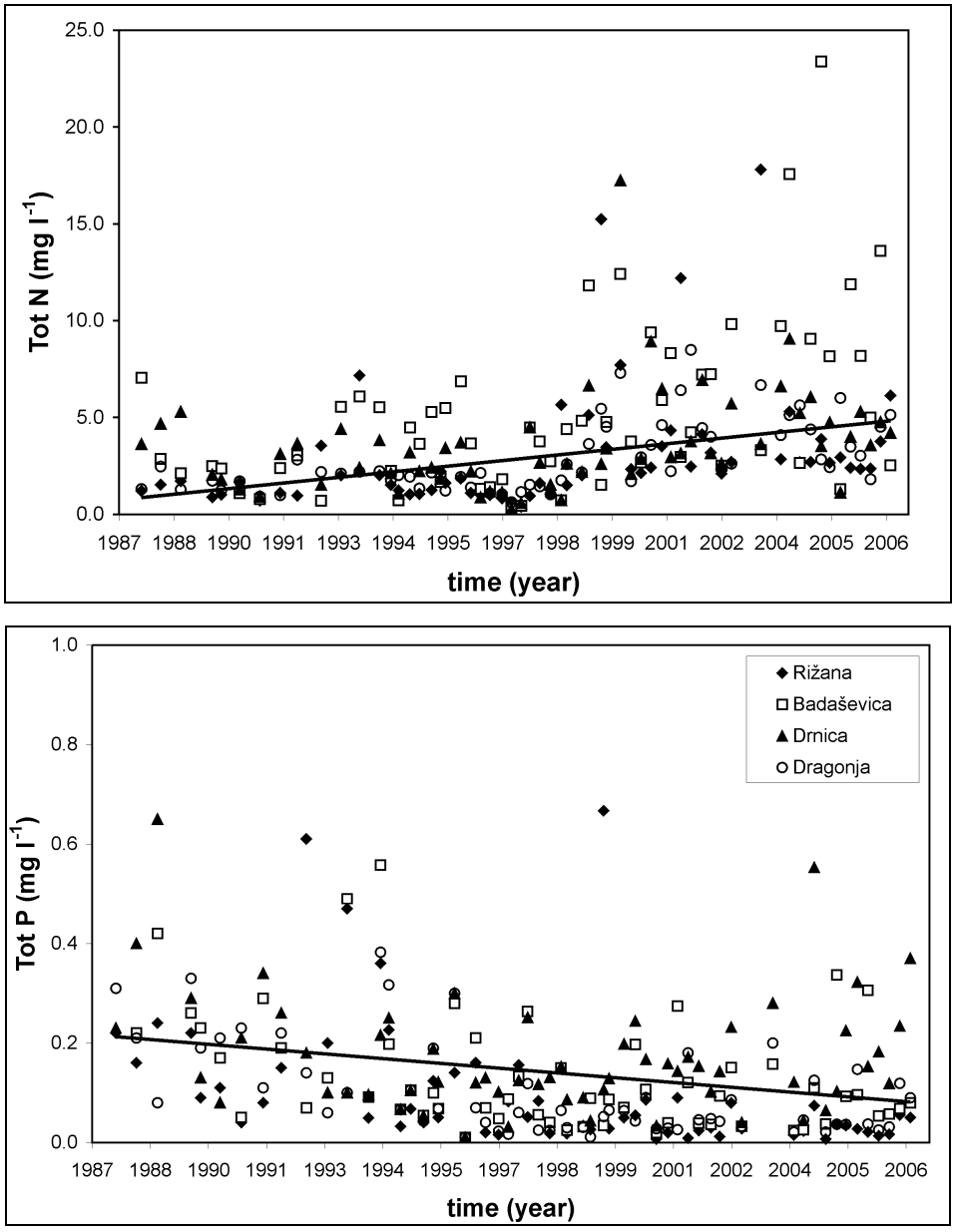

Fig. 2: Total nitrogen (top) concentrations and total phosphorus (bottom) concentrations in the river estuaries (Rižana, Badaševica, Drnica, Dragonja) along Slovenian coast in the 1988–2006 period.
Sl. 2: Koncentracije celokupnega dušika (zgoraj) in celokupnega fosforja (spodaj) v estuariju rek (Rižana, Badaševica, Drnica, Dragonja) vzdolž slovenske obale v obdobju 1988–2006.

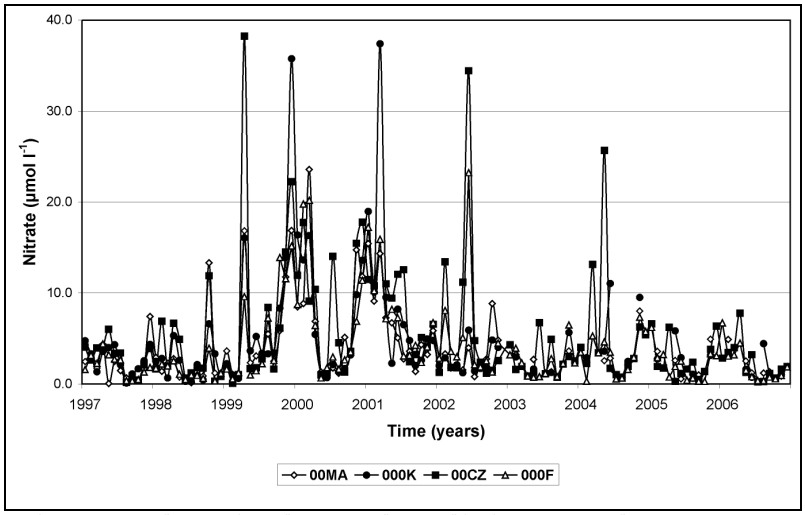

Fig. 3: Concentrations of nitrate in the surface layer in the Gulf of Trieste in the 1997–2006 period.
Sl. 3: Koncentracije nitrata v površinskem sloju v Tržaškem zalivu v obdobju 1997–2006.

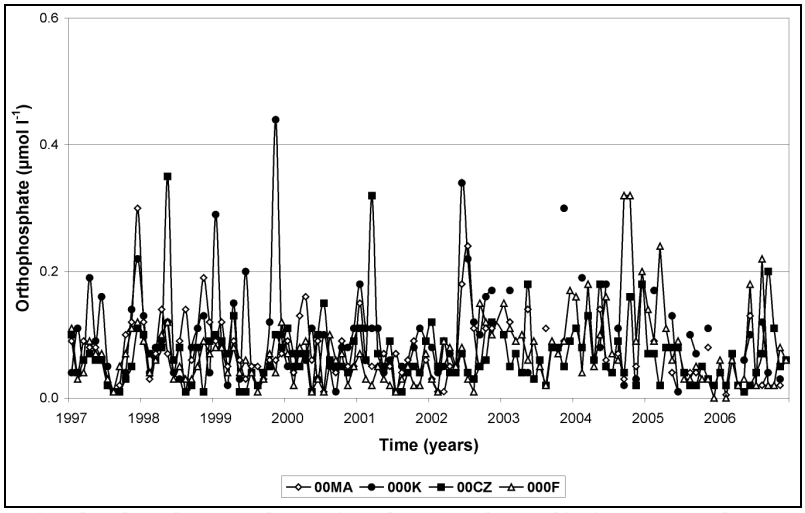

Fig. 4: Concentrations of orthophosphate in the surface layer in the Gulf of Trieste in the 1997–2006 period.
Sl. 4: Koncentracije ortofosfata v površinskem sloju v Tržaškem zalivu v obdobju 1997–2006.

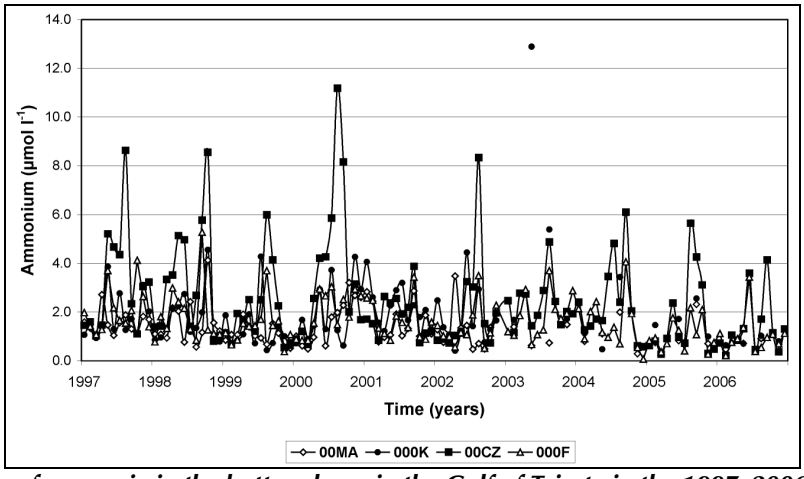

Fig. 5: Concentrations of ammonia in the bottom layer in the Gulf of Trieste in the 1997–2006 period.
Sl. 5: Koncentracije amonija v pridnenem sloju v Tržaškem zalivu v obdobju 1997–2006.

River inputs influence the dynamics of nutrients in the Gulf's sea water (Faganeli, 1983; Faganeli & Tušnik, 1983; Olivotti *et al.* 1986a, 1986b; Tušnik *et al.,* 1989; Mozetič *et al.*, 2005). High concentrations of inorganic nitrogen, especially nitrate, at the sea surface generally coincide with lower salinity. The concentration of nitrate in the surface is high in winter, low in summer and rises again in late autumn. Nitrate values generally range from 0.2 to 20.0 µmol l^{-1} with a peak around 40 µmol l^{-1} (Fig. 3). Concentrations of orthophosphate are generally low, the highest being below 0.5 µmol l^{-1} (Fig. 4). The values in the surface and in the bottom layer are fairly equal, with the dynamics varying from month to month and year to year. The ammonium concentrations are higher in layers above bottom (between 0.07 and 11.5 µmol l^{-1}) (Fig. 5), due to the intense regeneration processes during late summer and autumn. Higher ammonium concentrations coincide with increased concentrations of silicate and low concentration of oxygen (Turk *et al.,* 2000). Nutrient concentrations, N:P ratios in the ambient pool of inorganic nutrients, and bioassays indicate that both phytoplankton biomass and growth rates are P-rather than N-limited in the Northern Adriatic Sea (review in Malone *et al.*, 1999). Enrichment experiments proved that phosphorous has been the primary limiting element for the growth of phytoplankton as well as for bacterioplankton in the Gulf of Trieste (Mozetič *et al.,* 1998a; Cauwet *et al.*, 1999; Fajon *et al.*, 1999; Malej *et al.*, 2003).

Individual studies on the variability of organic nitrogen, organic phosphorus and dissolved organic matter along the Slovenian coast were performed only during the 1983–1990 period (Faganeli, 1983; Faganeli & Herndl, 1991). The influence of processes occurring in the marine sediment on organic carbon and nitrogen cycling in the sea water column is evident in the shallow Gulf of Trieste (Faganeli *et al.*, 1987; Herndl *et al.*, 1987; Bertuzzi *et al.*, 1996).

In recent years, the trophic status of the eastern part of the Gulf has been assessed by means of a numeric scale, *i.e.* the Trophic Index (TRIX) (Vollenwaider *et al.*, 1998). According to the TRIX classification criteria, the annual mean values of <4 correspond to elevated trophic state, scarce productive waters and good coastal quality condition. The mean annual value between 4 and 5 corresponds to good trophic state, moderately productive waters with occasional water turbidity, anomalous water colours and bottom water hypoxia episodes. The annual TRIX values between 5–6 and < 6 correspond to mediocre and bad trophic status, indicating very productive waters with high water turbidity, persistent anomaly in the water colour and regular anoxic episodes with high mortality rate of benthic organisms as well as other effects on the state of the ecosystem (*e.g.* decreased biodiversity). Apart from concentrations of dissolved inorganic nitrogen, total phosphorus and chlorophyll *a*, the proposed index also observes oxygen saturation. The TRIX calculated values at stations in coastal waters during the 2004–2006 period fell mostly between 3 and 4 (Fig. 6). Seasonal variability is characteristic, with lower values during the summer months and peak values in spring and autumn. Oscillations are more pronounced in the surface layer, with the TRIX values varying particularly at station in the middle of the Gulf. The TRIX values are higher in the inner part of the Bay of Koper, due to the effects of the Rižana River inflow, compared to the lower values along the transect from the middle of the Bay of Piran and at reference station (sampling station 000F) where the anthropogenic impact is negligible. Overall, according to the trophic TRIX and Fp indexes, calculated from the analyses of phytoplankton pigments biomarkers (Flander Putrle & Malej, 2003), the Gulf of Trieste could be classified as oligotrophic and in some parts as moderate eutrophic area, especially in the inner part of the Bay of Koper.

VARIABILITY OF PHYTOPLANKTON

A large spatial, seasonal and inter-annual variability of plankton has been documented for the Gulf of Trieste. Variability depends upon the combined effects of the river nutrient input, meteorological conditions, the degree of water column stratification and horizontal water advection from the middle Adriatic (Malej *et al.*, 1995; Mozetič *et al.*, 1998b; Malačič & Petelin, 2001). Studies on phytoplankton taxonomy have been performed since the mid-1800s and they covered mainly abundances of the most common species of microphytoplankton (review in Fanuko, 1980; Fonda Umani *et al.*, 1990; Harding *et al.,* 1999). Phytoplankton studies since the 1970s' have shown the importance of the autotrophic nanoplankton fraction (Fonda Umani *et al.*, 1990; Mozetič *et al.*, 1998b). Picoplankton fraction was evaluated only recently (Fanuko & Turk, 1990; Turk *et al.*, 2001a; Fuks *et al.*, 2005).

The variability of phytoplankton biomass and structure has been systematically followed along the Slovenian coast since 1976 (Fanuko, 1980, 1981; Mozetič *et al.*, 1998b, 2005). Seasonal, monthly, weekly and even daily sampling of phytoplankton demonstrated abrupt changes in abundance and community composition in phytoplankton assemblages (Fanuko, 1981, 1990). The relationship between nutrients and chlorophyll biomass has been studied in the Bay of Koper (Fanuko & Justić, 1986). More recently, a study performed over 14-year period evaluated trends of phytoplankton biomass in relation to physical and chemical parameters (Mozetič *et al.*, 2005). Although changes of nutrients through time were observed, there was no statistically significant trend in phytoplankton biomass that could be related to the eutrophication of the area (Mozetič *et al.*, 2005). The

overall means of chlorophyll *a* concentrations over the past 14 years (1989–2002) at five sampling stations were between 1.0 and 1.3 μg l^{-1} (Fig. 7) with absolute values ranging from 0.2 to 8.8 μg l^{-1}. The highest values are characteristic of the Bay of Koper and for the centre of the Gulf, while the lowest values are found at reference station, which is affected by oligotrophic waters from the southern Adriatic. Seasonal distribution of mean chlorophyll *a* values indicated great differences between months (Fig. 8). High values are measured from February to April, but after reaching the spring peak values, they are relatively modest in May and June. During the summer months, chlorophyll *a* concentrations are the lowest, while in October and November concentrations reach the second seasonal peak. Inter-annual differences between mean values are also quite significant, although no trend was detected in the 1989–2002 period (Fig. 9). Although phytoplankton biomass increased gradually from 1993, it dropped below 1 μg l^{-1} again in 2000; in 2001 and 2002, it did not differ significantly from the 1989–1991 period.

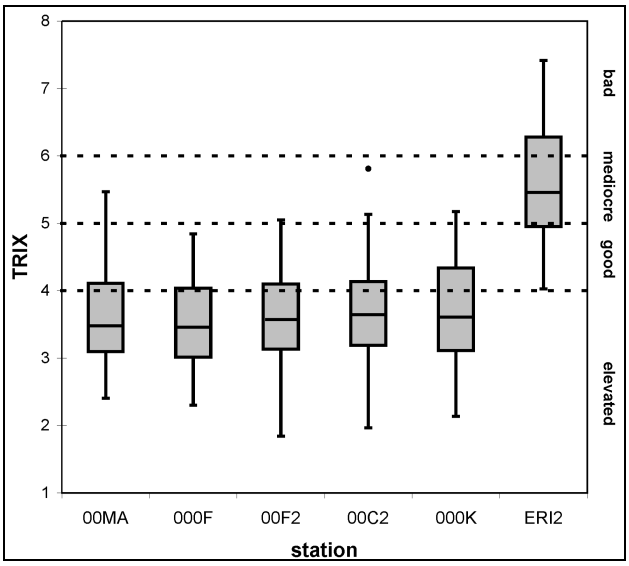

Fig. 6: Boxplots of TRIX index of the six sampling stations in the Gulf of Trieste (2004–2006 period).
Sl. 6: Boxplot graf za vrednosti TRIX indeksa na šestih merilnih mestih v Tržaškem zalivu (obdobje 2004–2006).

Eutrophication effects can also be displayed as a shift in algal species composition and an increase in the frequency and intensity of nuisance algal blooms. The most important groups of phytoplankton in the Gulf of Trieste are nanoflagellates that include various classes of autotrophic flagellates, and are followed by diatoms, dinoflagellates, coccolithophores and silicoflagellates. The results of monthly measurements of phytoplankton abundance in the 1989–2002 period showed a rather uniform annual distribution of total abundance with some inter-annual changes of particular phytoplankton groups (Mozetič & Francé, 2004). Diatoms and nanoflagellates maintain a very constant distribution and abundance throughout the years, but with different seasonal characteristics. Nanoflagellates are the dominant group in spring, while diatoms abrupt significantly in late autumn as well as in July. Dinoflagellates and coccolithophores are characterized by larger inter-annual changes, due to different occurrence/absence of seasonal blooms (Mozetič & Francé, 2004). This general picture of phytoplankton community structure and total abundance would suggest that physical-chemical and biological (*e.g.*, grazing) properties of the Gulf of Trieste remained relatively stable in the 1989–2002 period or they did not affect the structure at the group level.

As a complement to the classical optical methods of the group-specific phytoplankton biomass has been assessed using the reverse-phase high pressure liquid chromatography (HPLC) method. Results of the most prominent biomarker pigment indicated that the increase in chlorophyll is mainly due to diatoms, generally the most represented group during spring and autumn at the surface layer and below the pycnocline layer during the summer months (Flander Putrle *et al.*, 2000). This was also the main phytoplankton group found in mucilage aggregates (Baldi *et al.*, 1997; Flander Putrle *et al.*, 2000). In the spring period, the contribution of 19'-hexanoyloxyfucoxanthin containing phytoplankton (prymnesiophytes) has been significant preceding the accumulation of gelatinous material (Flander Putrle & Malej, 2003; Turk *et al.*, 2005b). Picoplankton is also a substantial component of the autotrophic biomass and production in the Gulf of Trieste (Fanuko & Turk, 1990; Turk *et al.*, 1992) as well as in the entire northern Adriatic (Fuks *et al.*, 2005). Unicellular cyanobacteria may represent 10–42% of the total autotrophic carbon, an estimate based on chlorophyll measurements. Some blooms of cyanobacteria start in spring, but during the summer cell densities increase rapidly and remain relatively high throughout the summer (Turk *et al.*, 2001a; Fuks *et al.*, 2005).

VARIABILITY OF OTHER MICROORGANISMS

The species composition of the bacterial community is largely unknown. The bacterioplankton assemblage has been treated, until now, as a single group, classified by dominant cell shape and determined by abundance and activity. Free living heterotrophic bacteria are not randomly distributed vertically and horizontally, according to concentration gradients in microenvironments in order to maximize dissolved organic matter uptake. The abundance of heterotrophic bacteria (0.7 to 2.0×10^9 cells l^{-1}) is within the range reported for other coastal areas in the northern Adriatic Sea (Turk, 1992;

Turk & Hagström, 1997; Turk *et al.*, 2001a). The bacterial production measured with the tritiated tymidine incorporation method varied between 0.5 and 16 µg C l^{-1} d^{-1}, showing seasonal and diel variations. The ratio between production and biomass (P/B ratio) indicated turnover of between 0.28 and 1.1 times per day, with higher rates during the summer. Similar results were obtained by measuring the bacterial growth rates *in situ*, using dialysis bags (Herndl *et al.,* 1987). Bacterial nutrient incorporation and remineralization is controlled by the substrate's chemical composition and bacterial gross growth efficiency.

Bacterial abundance shows a remarkable stability in most aquatic systems. The seasonal dynamics of heterotrophic organisms at different trophic levels and function in pelagic communities was first studied during the 1986–90 period in sea waters of the eastern part of the Gulf (Northern Adriatic) (Turk, 1992). Monthly sampling of microorganisms and dissolved carbohydrates over the two-year period in the Gulf of Trieste suggested that accumulation of dissolved carbohydrates occurred when bacterial abundance was controlled by predators (Turk *et al.*, 2001a). During the summer months, when oligotrophic conditions prevailed, the processes of transformation of organic matter through a microbial loop type of food web are important in the water column. The seasonal fluctuation of bacterial standing stocks and bacterial growth are not correlated over time due to mortality and predation.

Most of the bacterial biomass is utilized by protozoa, as shown by measurements of protozoa grazing on bacteria and the recorded growth of nanoflagellates (Turk *et al.*, 1992; Turk & Hagström, 1997). Heterotrophic nanoflagellates are the major consumers of bacteria, since the flagellates can efficiently capture marine bacteria. The number of heterotrophic nanoflagellates varied between 0.4 and 3.5×10^6 cells l^{-1} in the Gulf of Trieste. The variation in numbers and their relationships with bacteria have been shown in a two-stage chemostate experiment and in diel measurements of *in situ* measurements in the Gulf of Trieste (Turk *et al.*, 1992). In the bag experiment, ^{14}C-labeled bacteria were incorporated into nanoflagellate size fractions, and only a limited amount of label was transferred into larger size fractions, due to predation. The range of predation varied between 2 and 14×10^7 cells l^{-1}, which represent an ingestion rate of between 44 and 85 bacterial cells per flagellate per hour.

While consuming bacteria, nanoflagellates release a substantial amount of dissolved organic matter, such as dissolved DNA. The degradation and transfer of phosphorous from ^{32}P-labeled plasmid DNA added to seawater samples from the station in the Gulf of Trieste indicated a rapid turnover of DNA (4.7 hours) mediated a release of inorganic phosphorous. Furthermore, a tight coupling between released inorganic phosphorous and uptake by nano- and picoplankton size fraction was demonstrated. In P-limited systems, the coupled uptake of released phosphate has been shown to be effective, and bacteria compete efficiently with algae (Turk *et al.,* 1992). Bacteriophages have been also suggested as an important factor for bacterial mortality in the Gulf of Trieste (Baldi *et al.,* 1997; Stopar *et al.*, 2004). The total viral abundance ranged between 2.5 and 29×10^9 per litre. According to virus morphology determined by transmition electron microscopy, bacteriophages represent a significant (26%) fraction of the virus community. A relatively high occurrence of lysogenic bacteria in the Gulf of Trieste suggests that temperate phages may be important component of virioplankton (Stopar *et al.*, 2004). More recent results also showed that the bacterial lysate released as dissolved organic matter and their nutritional quality determine the growth rate and activity of other bacteria (Odić *et al.*, 2007).

Beside nanoflagellates, some studies suggest that ciliates and certain other protists are important consumers of bacteria and phytoplankton, which might influence the food web structure and function. An overview of seasonal patterns in organism abundance and biomass, species composition and the ecological roles of micro-consumers for the Northern Adriatic are presented by Coats & Revelante (1999). Little information is available on microzooplankton predation in the Gulf of Trieste (Lipej, 1992; Lipej *et al.*, 1997; Coast & Revelante, 1999). Ciliated protozoa constitute 89–99% of total microzooplankton abundance and 12–52% of the community biomass (Coats & Revelante, 1999). The study of inter-annual variations of plankton food webs confirmed high year-to-year variations in microzooplankton and mesozooplankton abundances and taxonomic composition during the 1999–2002 period (Fonda Umani *et al.*, 2005). Significant decrease in abundance of ciliate protozoa due to the total number of microzooplankton and dominance of *Oithona nana* has been recorded during the presence of mucous aggregates (Kršinić, 1995).

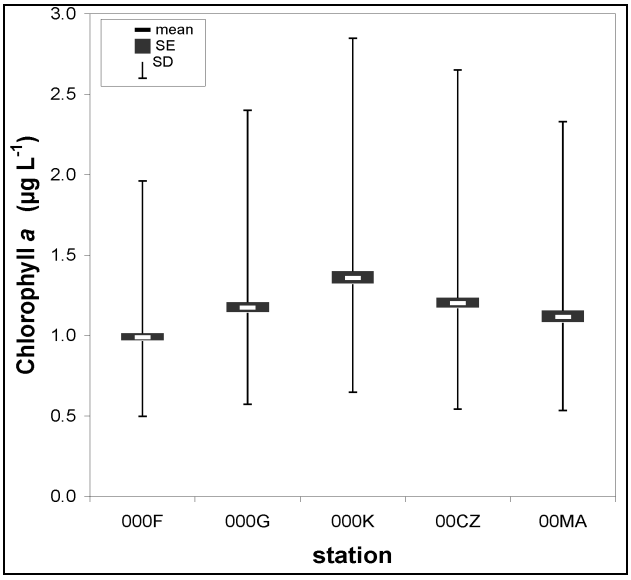

Fig. 7: Overall means of chlorophyll a concentrations (along the water column and in 14-year period) of five sampling stations in the Gulf of Trieste, 1989–2002 period.
Sl. 7: Celotne srednje vrednosti koncentracij klorofila a (vzdolž vodnega stolpa in v 14-letnem obdobju) na petih merilnih mestih v Tržaškem zalivu, obdobje 1989–2002.

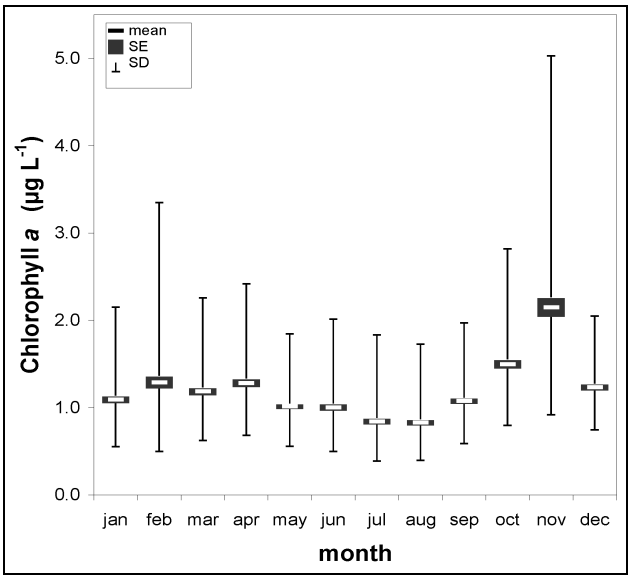

Fig. 8: Seasonal distribution of monthly means of chlorophyll a, consdering a 14-year period (1989–2002) and five sampling stations in the Gulf of Trieste (the same as in figure 7).
Sl. 8: Sezonska porazdelitev mesečnih srednjih vrednosti klorofila a, upoštevaje 14-letno obdobje (1989–2002) in pet merilnih mest v Tržaškem zalivu (iste kot na sliki 7).

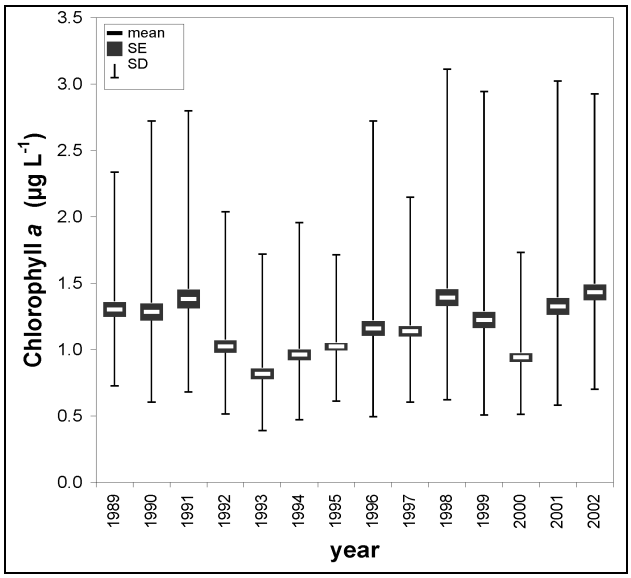

Fig. 9: Variations of annual means of chlorophyll a, consdering a 14-year period (1989–2002) and five sampling stations in the Gulf of Trieste (the same as in figure 7).
Sl. 9: Variacije letnih srednjih vrednosti klorofila a, upoštevaje 14-letno obdobje (1989–2002) in pet merilnih mest v Tržaškem zalivu (iste kot na sliki 7).

VARIABILITY IN PRIMARY PRODUCTION

Several studies of primary production have been performed on the Slovenian and Italian sides of the Gulf (Faganeli *et al.*, 1982; Fonda Umani & Ghirardelli, 1988; Malej *et al.*, 1995; Cabrini *et al.*, 2002; Cantoni *et al.*, 2003), with results indicating large variations.

First measurements of primary production in the southeastern part of the Gulf date back to the early 80's (July 1979 – June 1980; Faganeli *et al.*, 1982) and results vary from 0.8–14 mg C m^{-3} d^{-1}, giving an average annual estimate of 42 g C m^{-2} a^{-1}. Daily values of primary production measurements performed a decade later, i.e. in 1992 (Malej *et al.*, 1995), are higher than those reported by Faganeli *et al.* (1982), ranging from 2.3–57 mg C m^{-3} d^{-1}. However, an annual estimation was not made due to incomplete sampling across the seasonal cycle.

In the northwestern part of the Gulf, the latest primary production measurements encompass the period from October 1999 to February 2001, including the year 2000 with mucilage event (Cantoni *et al.*, 2003). The maximal daily rates (190 mg C m^{-3} d^{-1}) are much higher as compared to the southeastern part (see above), whereas the lowest rates (2.4 mg C m^{-3} d^{-1}) are very similar. However, the comparison of daily production rates, especially the highest one, between the southeastern and northwestern part of the Gulf is not strictly consistent. The latter measurements from 1992 in the south-

eastern part did not cover the entire annual cycle, thus the highest rate could be well underestimated.

Daily and annual primary production rates indicate relatively low pelagic production and are lower for the entire Gulf of Trieste compared to the estimates reported for the northern Adriatic. Residence time of freshwater and availability of the nutrients determine the rates of production in the Gulf of Trieste (Cantoni *et al.*, 2003). Comparisons of annual phytoplankton production with riverine nutrient inputs suggest that recycling nutrients support about 50% of phytoplankton production in the northern Adriatic (Harding *et al.,* 1999).

PLANKTON BLOOMS

In spite of the frequent plankton surveys carried out since the beginning of the 20th century, only few plankton records on blooms in the Adriatic Sea are at hand for the period prior to the 1970s (Fanuko, 1990; review in Sellner & Fonda Umani, 1999). In the Gulf of Trieste, algal blooms occurred more frequently in shallow areas, such as lagoons, bays and harbours (Tab. 2), but with lower intensity and frequency along the Slovenian coast compared to more eutrophic areas along the western coast, *i.e.* Emilia-Romagna region. Events resulting in visible water discolorations are linked mainly to highly stratified systems and the spring/summer period. For the Gulf of Trieste, there is a historical record from November 1902 on blooms of heterotrophic dinoflagellate *Noctiluca scintillans* (Sellner & Fonda Umani, 1999). A large-scale red tide of *N. scintillans* covering the entire Northern Adriatic was observed in June 1977 (Fonda Umani *et al.*, 2004). A red tide caused by the same organisms re-appeared in the summers of 1980, 1981 and 1983 (Malej, 1983; Honsell *et al.*, 1989; Fonda Umani *et al.*, 2004). After that, *N. scintillans* remained a constant plankton component until 1997, when summer bloom appeared yet again. During the 1970s, aggregations of *Peridinium ovum,* causing discoloration of the water, were recorded (Bussani, 1974). In June and September 1977, *Lingulodinium polyedrum* (syn. *Gonyaulax polyedra*) bloom was observed (Fonda Umani, 1985). Discoloration of sea water due to *Exuviella marina* was recorded in Trieste Harbour in June 1981. The sea was coloured brown due to *L. polyedrum* bloom also in 1978 and again in the entire Gulf of Trieste in September 1982. At the end of May 1983, *Scrippsiella faeroense* bloom was recorded in the inshore areas (Fonda Umani & Honsell, 1984), and there was a large bloom of *Gymnodinium* spp. in the whole northern Adriatic in the autumn 1984 (Artegiani *et al.*, 1985). During the 1986–89 period, several winter diatom blooms were recorded, such as *Hemiaulus hauckii* bloom in December 1987, which lasted until February 1988 with maximum chlorophyll *a* concentration of 12 µg l^{-1} (Fanuko & Turk, 1990). Other blooms were also recorded, such as that of silicoflagellate species *Distephanus speculum* at a depth of 20 m (up to 0.6×10^{6}

Tab. 2: Records of plankton blooms and unusual events in the Gulf of Trieste during the 1970-2005 period.
Tab. 2: Zapisi planktonskih cvetenj in nenavadnih dogodkov v Tržaškem zalivu v obdobju 1970-2005.

Species / event	Year	Author
Peridinium ovum	1973	Bussani, 1974
Lingulodinium polyedrum (syn. *Gonyaulax polyedra*)	1977, 1978, 1982	Fonda Umani, 1985; Fanuko, 1990
Noctiluca scintillans	1977, 1980,1981, 1983, 1990, 2004	Cassinari *et al.*, 1979; Malej, 1983; Honsell *et al.*, 1989; Fonda Umani *et al.*, 2004
Exuviella marina	1981	Fonda Umani, 1985
Gonyaulax polyedra	1982	Fonda Umani, 1985
Scrippsiella faeroense	1983	Fonda & Honsell, 1984
Distephanus speculum	1983	Fanuko, 1989
Rhizosolenia alata f. *gracillima*	1983	Fanuko ,1984
Gymnodinum spp.	1984	Artegiani *et al.*, 1985
Prorocentrum micans	1984	Fanuko, 1990
Hemiaulus hauckii	1987/88	Fanuko & Turk, 1990
mucus aggregates	1988,1989,1991,1997, 2000, 2001, 2002, 2004	Fonda Umani *et al.*, 1989; Stachowitsch *et al.*, 1990; Sellner & Fonda Umani, 1999; Malej *et al.*, 2001; Precali *et al.*, 2005

cells l^{-1}), which may have contributed to anoxic conditions in August 1983 (Fanuko, 1989). Water discoloration by summer blooms of *Rhizosolenia alata* f. *gracillima* diatom were recorded along the Istrian coast in 1922, and appeared regularly in the 1977–1983 period (with abundance of $0.3–0.5\times10^6$ cells l^{-1}) (Fanuko, 1984a). A monospecific red tide of *Prorocentrum micans* dinoflagellate was recorded in the autumn of 1984 (Fanuko, 1990). The records of dominant phytoplankton bloom species in the Gulf of Trieste are summarized in Table 2 for the 1970–2005 period.

OCCURRENCE OF TOXIC PHYTOPLANKTON SPECIES

Increased abundance of some dinoflagellate and diatom species may sometimes have harmful consequences on the marine organisms as well as on humans. Among various types of intoxication, three are of major concern in the Gulf of Trieste, since the causative organisms are commonly found in the northern Adriatic. First is the diarrhetic shellfish poisoning (DSP), which is caused mainly by various dinoflagellate species of the genus *Dinophysis*. Other potentially toxic species that also produce DSP-related lipophilic toxins (yessotoxins) are *L. polyedrum* and *Protoceratium reticulatum*. Both are commonly found in the phytoplankton community of the Gulf of Trieste. Second, and more dangerous, is paralytic shellfish poisoning (PSP), which is caused by some dinoflagellate species of the genus *Alexandrium*. Recently (in 2006), analyses of ASP (amnesic shellfish poisoning) commenced due to regular occurrence of some diatom species of the genus *Pseudo-nitzschia*. At shellfish farms on the Slovenian coast, DSP toxins occur almost every year. Temporary bans of shellfish farms from 1989 onwards are quoted in Sedmak *et al.* (2003).

The first documented outbreak of DSP in Slovenian coastal waters dates from the autumn-winter 1989 period (Fanuko *et al.*, 1989; Sedmak & Fanuko-Kovačić, 1991); it was related to the occurrence and increased abundance of various *Dinophysis* species. Besides this event, several authors (Honsell *et al.*, 1992, 1996; Mozetič *et al.*, 1997) reported on the regular occurrence of toxic dinoflagellates over short time (mainly warm) periods in the Gulf of Trieste.

A longer series of data was evaluated for the 1995–2003 period (Francé & Mozetič, 2006a), showing the seasonal distribution and inter-annual variations of *Dynophysis* species. Comparison between 4 most recurrent *Dinophysis* species and environmental factors showed that only one and the most abundant species (*D. sacculus*) was significantly correlated to the specific environmental conditions (i.e. thermal and haline stratification), while none of the inorganic nutrients influenced the distribution and abundance of *Dinophysis* spp. *D. sacculus* appears to be influenced by freshwater inputs in other coastal Mediterranean areas as well (Caroppo, 2001; Villa *et al.*, 2001).

Contrary to the seasonal dynamics of the genus *Alexandrium*, which is found in relatively low numbers in colder months (early spring, autumn) but does not form toxic blooms, the abundance of *Dinophysis* spp. starts to increase with the warming of the sea in May and reaches its peak during the summer-early autumn months (Francé & Mozetič, 2006b).

JELLYFISH BLOOMS

Other massive plankton events in the northern Adriatic were outbreaks of large jellyfish, which may have a significant impact on fisheries, tourism and the food web trophic structures (Malej, 2001). Although eight scyphomedusae species have been determined over the last 150 years in the northern Adriatic (references in Purcell *et al.*, 1999), only a few of them have been observed in large numbers. Repeated massive occurrences of jellyfish in the northern Adriatic as well as in the Gulf of Trieste were recorded for *Aurelia aurita, Chrysaora hysoscella, Cotylorhiza tuberculata*, *Pelagia noctiluca* and *Rhizostoma pulmo* (Malej, 2001) (Tab. 3). *Aequorea forskalea* were mentioned several times since the 1970s. Most information is available for *P. noctiluca*, which was recorded in masses during two periods, during 1910–1914 and 1976–1986 (Malej, 1981, 2001; Malej & Vukovič, 1986; UNEP, 1991) and again during 2004–2006. Blooms of *P. noctiluca* have been shown to exert a significant influence on net zooplankton production, structure modification and releasing a considerable amount of nutrients (Malej, 1989).

Aurelia sp. has been abundant in the 1994–1997 period (Malej, 1995, 2001; Purcell *et al.*, 1999) and from 2004 on. Studies on *R. pulmo* started only recently (Malej *et al.*, 2006), but there has been no systematic study regarding the abundance and distribution of *C. tuberculata* and *C. hysoscella*.

Another plankton group, ctenophores, may be abundant in the Gulf of Trieste and the entire northern Adriatic in colder parts of the year (Malej, 2001). Enormous numbers of pteropod *Creseis acicula* were recorded in September 1974 and again in Jul/Aug 1990 near shore in the Bay of Piran (Malej, 2001). This species was again noted in 2007, but was not so abundant.

Tab. 3: Records of massive gelatinous zooplankton occurrence in four periods from 1971 to 2006 in the Gulf of Trieste.
Tab. 3: Zapisi masovnega pojavljanja želatinoznega zooplanktona v štitih zaporednih obdobjih v letih 1971–2006 v Tržaškem zalivu.

Organism	1971–1980	1981–1988	1989–2000	2001–2006
Hydromedusae				
Aequorea forskalea	+	+	++	++
Scyphomedusae				
Aurelia aurita	+	+	++	+
Chrysaora hysoscella		+	+	+
Cotylorhiza tuberculata	++	+		++
Pelagia noctiluca	++	++		+
Rhizostoma pulmo		+	+	+++
Ctenophora	+	+	++	++
Gastropoda				
Creseis acicula	++		+	+
Thaliacea	+	++	+	++

+ Event was observed once in the period
++ Event was observed several times in the period
+++ Event was observed every year during the period

OCCURRENCE OF MUCILAGE

Over the last 18 years, a shift from red tides to mucilage phenomena has been observed. Since 1988, almost every year a mucilage phenomena of different intensity appeared, manifested as dense macroflocs, cobweb, clouds, blankets, creamy/gelatinous layer (Stachowitsch *et al.*, 1990; Precali *et al.*, 2005) (Tab. 3).

In the Adriatic Sea, the occurrence of mucilage has been observed for at least two centuries: a record by Venetian authorities dated from 1729 exists, reporting mucilage masses covering coastal waters and making fishing impossible. This phenomenon was described for the first time in the Gulf of Trieste in 1872 (Syrski, 1872). The 18th and 19th century chronicles of the northern Adriatic towns and scientific journals reported similar events in 1873, 1880, 1881, 1892, 1893, 1903, 1905, 1906, 1920, 1928, 1930 and 1931 (Fonda Umani *et al.*, 1989). Some describe this problem as local, while others mention mucilage masses spreading all over the northern Adriatic. More recently, large-scale mucilaginous aggregate formations occurred during the springs/summers of 1988, 1989, 1991, 1997, 2000, 2001, 2002 and 2004. The typology of aggregates was described by Stachowitsch *et al.* (1990) and more recently by Precali *et al.* (2005).

Large flocks reaching several cm are seasonally abundant in the northern Adriatic and have been generally related to decaying diatom blooms (Herndl & Peduzzi, 1988). Occasionally, masses of mucilage remain suspended in the water column of the northern Adriatic for up to several months during the summer stratified season (May to September), with the phenomenon dissipating by the time of autumnal vertical mixing (Degobbis *et al.,* 1995; Malej *et al.,* 1995; Sellner & Fonda Umani, 1999). The occurrence of mucilage is not limited to the Adriatic Sea. It is known all over the Mediterranean, especially in Greek waters, in the Tyrrhenian Sea and around the coasts of Sicily. In these areas, however, the mucilage masses usually stay in deeper layers of the sea and rarely emerge on the surface. Also, the duration is shorter than in the northern Adriatic. A similar phenomenon is known to occur in the Northern Sea, off the coasts of France, Belgium, The Netherlands and Germany, where foamy and mucilaginous masses accumulate in spring. Similar event to northern Adriatic mucilage is also reported from the coastal waters of New Zealand, where a dinoflagellate species *Gonyaulax hyalina* is repeatedly involved in the release of polysaccharide exudates and subsequent formation of gelatinous macroaggregates (MacKenzie *et al.*, 2002). However, the intensity of this phenomenon seems to be unique to the northern Adriatic area, and when it occurs, mucilage accumulates in the water column and at the surface covering up to several hundreds of square kilometres, creating serious problems for tourism and fisheries (Rinaldi *et al.,* 1995; Funari *et al.,* 1999). For the summer 2000 mucilage event in the Gulf of Trieste, Malej *et al.* (2001) calculated that the total of integrated mucilage-associated particulate carbon was 82 g C m^{-2}.

In recent years, several hypotheses for explaining mucilage development in the northern Adriatic have been proposed. The role of phytoplankton has been tested in combination with specific environmental factors and changes in phytoplankton community structure (Degobbis *et al.*, 1999), nutrient limitation (Fajon *et al.*,

1999), phytoplankton cell lysis (Baldi *et al.,* 1997), and reduced grazing pressure (Malej & Harris, 1993). The extensive cell lysis was supported by analyses using scanning confocal laser microscopy in combination with different fluorescent molecular probes and lipid analyses (Baldi *et al.*, 1997). Phytoplankton response to the addition of different combinations of inorganic N, P and Si nutrients as well as rain and river water was studied in enclosure experiments (Mozetič *et al.*, 1998a; Malej *et al.*, 2003). The enrichment of nitrogen and phosphor accumulation and the release of polysaccharides by planktonic cells were studied in a controlled experiment (Fajon *et al.*, 1999; Malej *et al.*, 2003). These experiments showed that the microflagellate-dominated community released more dissolved organic carbon per unit biomass. At the transition to the stationary phase, the decay of autotrophic community was accompanied by a net accumulation of carbohydrate rich dissolved organic carbon. Azam *et al.* (1999) emphasized a sustained bacterial activity and the role of "slow-to-degrade" organic matter. Common to all proposed mechanisms are the steps of production and accumulation of dissolved organic matter (DOM) resistant to degradation. Understanding the processes that channel carbon flux in favour of DOM that is slow to degrade thus seems crucial for explaining the mucilage phenomenon in the northern Adriatic. Aluwihare & Repeta (1999) showed that a large fraction of high molecular weight DOM consisted of structurally related acylated polysaccharides. They demonstrated production of these compounds by phytoplankton and/or bacteria and accumulation of acylated polysaccharides after bacterial degradation in culture experiments. A similar macromolecular structure composed of carbohydrates was found for macroaggregates from the northern Adriatic (Kovač *et al.*, 2002, 2004). Nature of suspended particulate matter during density stratification in shallow coastal waters and characterization of macroaggregates has been studied by Kovač & Faganeli (1991) and Kovač *et al.* (1998, 2004, 2005).

Large mucus aggregates influence microzooplankton and mesozooplankton temporal and spatial variability directly by decreasing the naupliar copepod population (Kršinić, 1995) or changing feeding capability (Malej & Harris, 1993; Bochdansky & Herndl, 1995) and indirectly by altering food web structure and function (Cabrini *et al.*, 1992; Cataletto *et al.*, 1996; Fonda Umani *et al.*, 2005).

Mucus aggregates can severely affect some fish species that breed during the warm period of the year, for it is hard for the eggs to survive if trapped in mucilage mass. The fish that breed in the critical period are mostly sardines *(Clupea pilchardus)* and anchovies *(Engraulis encrasicholus),* but others suffer as well, for instance flounders *(Platichthys flesus),* sand smelt *(Atherina boyeri),* and whiting *(Gadus merlangus).* When the mucilage sinks to the bottom, it physically covers the organisms living on the bottom or in the sediment and thus makes normal physiological processes impossible. Filtering organisms (sponges and tunicates) are severely affected, as are some other organisms, such as coelenterates. Below the sedimented mucilage, total lack of oxygen occurs, which additionally affects the organisms living on the bottom, for they can not escape the mucilage area. In 2000, increased mortality of *Pitaria chione* was recorded in the Gulf of Trieste as well as mortality of various scallops *(Chlamys* spp., *Pecten jacobaeus*).

HYPOXIA AND ANOXIA

Periods of oxygen depletion below the thermocline have been observed almost every year in the Gulf of Trieste (Stachowitsch, 1984; Faganeli *et al.*, 1985; Malej *et al.*, 1989; Stachowitsch *et al.*, 1990; Malej & Malačič, 1995). In the last two decades, hypoxias have been occurring in the central part of the Gulf in late summer or in early autumn (August–October) (Malej & Malačič, 1995), while anoxia occurs occasionally and was recorded in 1974, 1980, 1983, 1987, 1989, and 1990. The most destructive anoxia was recorded in September 1983 (Stachowitsch, 1984; Faganeli *et al.*, 1985); it lasted for two weeks, covering one third of the Gulf. In the affected area, all the attached, partially attached and poorly mobile demersal animals died at that time. Almost the entire benthic associations of brittle star *Ophiotrix quinquemaculata*, sponges of the genus *Reniera* and ascidians of the genus *Microcosmos* (Stachowitsch, 1984) were destroyed, and have not recovered completely (Stachowitsch, 1991, 1992; Stachowitsch & Fuchs, 1995).

CONCLUSIONS

Increasing population in the coastal zone, land-use changes and land base sources of pollution influence the quality of coastal water and ecosystems. Eutrophication-related phenomena and the sanitary quality of the beaches appear to be the main coastal environment problems in the Adriatic, particularly in the Gulf of Trieste. Our study was concentrated on overview of literature and analyses of recent data for the Slovenian sea.

In semi-enclosed seas, such as the Gulf of Trieste, eutrophication problems are mainly subject to the combined effects of oceanographic, chemical and biological interactions. The highly variable conditions in the pelagic ecosystem influence the frequency of blooms, occurrence of harmful toxic algal species, swarming of gelatinous zooplankton, the mucilage phenomenon and hypoxia/anoxia events. Improper use of land and point-source discharges of untreated wastewater and sewage continue to pollute estuarine and inner parts of the bays. The trophic conditions of Slovenian coastal waters were assessed as TRIX index on the basis of chemical and

biological parameters. The sea was characterized as oligotrophic to mesotrophic, indicating worse tropic status in the inner part of the Bay of Koper. Episodic high nutrient deposition may have a significant impact on microplankton as well as on the intensity and frequency of eutrophication phenomena. The wastewater discharges close to the coast may pose a health risk to anyone who comes into contact with the water or who consumes food collected from the sea water. An observation system should be designed in order to gather better scientific and technical information to useful early warning and to decide on suitable measures of intervention. A coastal area is the most valuable and dynamic region, so an integrated approach should be adopted to provide data for the optimization of control measures and clear indications for decision-makers.

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PREGLED POJAVOV EVTROFIKACIJE IN DRUGIH NENAVADNIH DOGODKOV V SLOVENSKEM MORJU (TRŽAŠKI ZALIV, JADRANSKO MORJE)

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POVZETEK

Evtrofikacija je pomemben dejavnik degradacije morskih ekosistemov in je v veliki meri posledica človekovega vpliva na okolje. Kljub številnim spoznanjem v zadnjih 30 letih ostaja evtrofikacija ključen problem, ki vpliva na kakovost obalnih območij, še posebno polzaprtih morij, kakršen je tudi Tržaški zaliv. Intenziteta in pogostost pojavov, povezanih z evtrofikacijo, sta odvisni predvsem od spleta razmer vnosa hranil s kopnega, meteoroloških razmer, stratifikacije vodnega stolpa in horizontalne advekcije vodnih mas.

Podan je pregled literaturnih podatkov pojavov in posledic evtrofikacije v Tržaškem zalivu s poudarkom na dominantnih pelaških združbah obalnega ekosistema, posebno na bakterijski in fitoplanktonski abundanci in produkciji, frekvenci planktonskih cvetenj, pojavljanja toksičnih vrst fitoplanktona in želatinoznega zooplanktona ter pojavljanja sluzenja morja in hipoksije/anoksije.

Ključne besede: evtrofikacija, hranila, planktonska cvetenja, anoksija, sluzasti agregati, Tržaški zaliv

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POLYAROMATIC HYDROCARBONS POLLUTION ASSESSMENT OF THE SLOVENIAN SEA

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ABSTRACT

The paper assesses pollution of the Slovenian sea in terms of polyaromatic hydrocarbons content in sediment samples and mussels. For this purpose, fluorescence spectroscopy was applied as a screening method. Elevated concentrations of polyaromatic hydrocarbons were obtained in municipal harbours of the three Slovenian coastal cities, as well as in marinas along the coast. The Bay of Koper is more polluted in comparison to the Bay of Piran, which seems to be the less polluted area of Slovenian coastal waters. The Bay of Koper is affected by various port activities and maritime traffic. In the central part of the Gulf of Trieste, a certain influence of the city of Trieste with its port and maritime traffic was observed. In general, the Slovenian sea could be considered as moderately polluted.

Key words: polyaromatic hydrocarbons, pollution, sediments, mussels, fluorescence spectroscopy, Slovenian sea

VALUTAZIONE DI INQUINAMENTO IN MARE SLOVENO CON L'AUSILIO DI IDROCARBURI POLIAROMATICI

SINTESI

Nell'articolo viene presentata la valutazione dell'inquinamento del mare sloveno con l'ausilio delle concentrazioni di idrocarburi poliaromatici in campioni di sedimento e bivalvi. A tale scopo è stata adoperata la spettroscopia di fluorescenza. Concentrazioni elevate di idrocarburi poliaromatici sono state registrate nei mandracchi dei tre comuni costieri come pure nelle marine costiere. La baia di Capodistria è risultata più inquinata di quella di Pirano, che sembra essere l'area meno inquinata del mare sloveno. La baia di Capodistria viene condizionata dal porto e dal traffico navale. La parte centrale del Golfo di Trieste risente dell'influsso della città di Trieste, del rispettivo porto e del traffico navale. In conclusione, il mare sloveno risulta essere moderatamente inquinato da idrocarburi poliaromatici.

Parole chiave: idrocarburi poliaromatici, inquinamento, sedimenti, bivalvi, spettroscopia di fluorescenza, mare sloveno

INTRODUCTION

Hydrocarbons of natural and anthropogenic origin are widely distributed in different environmental compartments, i.e. soils, sediments, natural waters and biota. The awareness of the various sources of introduction into the natural environment, dispersal of these compounds, transport mechanisms and the concentrations in different parts of the environment are very important to adequately asses the state of the environment. The most important sources of pollution by hydrocarbons are oil seepage, oil spillage, combustion of various fossil fuels, traffic, domestic and industrial waste waters and sewage, as well as urban runoff (IMO, 1993). Because of their low solubility in water and rather low vapour pressures, the adsorption of hydrocarbons onto solid particles is a very important process in the natural environment (Means *et al.*, 1980). Hydrocarbons are relatively stable in the natural environment and they accumulate in sediments and biological communities (Guzella & de Paolis, 1994; Quintero & Diaz, 1994). For this reason, sediment and biota samples are usually used for the analyses since the concentration in seawater is usually very low due to the fast dilution. The most used marine organisms for this purpose are mussels. They are widespread in coastal waters, and owing to their filtrating ability they accumulate contaminants in their tissue.

The study of the impact and fate of hydrocarbons is therefore of great importance, especially in marine coastal waters since these areas are biologically active and receive considerable pollutant inputs from land-based sources via coastal and river runoff.

The aim of the present work was to investigate the state of marine environment in the Slovenian sea in terms of pollution with polyaromatic hydrocarbons. For this purpose, sediment samples and mussel tissue *(Mytilus galloprovincialis)* collected in 2005 and 2006 were analyzed. Sediment samples were not separated according to the grain size. It is well known that the adsorption of different compounds onto sediment particles is dependant on the grain size since smaller particles have bigger specific area for the adsorption. The aim of this work was merely to compare different coastal areas and to assess the pollution with polyaromatic hydrocarbons and not a detailed study of polyaromatic hydrocarbons distribution. The content of polyaromatic hydrocarbons was determined using UV fluorescence spectroscopy. This technique was established for the determination of total hydrocarbons, although the major part of fluorescence arises from polyaromatic hydrocarbons (Mason, 1987). This method is quite fast and very sensitive. Its weakness could be that it can only provide information concerning the classes of compounds (Mason, 1987) whereas its application for the determination of the concentrations of individual compounds is rather limited (Ehrhardt & Knap, 1989). On the other hand, the fluorescence may also be due to degradation products generated from oil in the natural environment (Ehrhardt & Knap, 1989). These compounds are important constituents of the unresolved complex mixture (UCM), determined usually as a background signal in GC chromatograms. The UCM was considered a better measure of the level of petroleum hydrocarbons than the resolved components (Farrington *et al.*, 1982). In addition, the fluorescence spectroscopy is less susceptible to the influence from biogenic compounds, since biological tissue does not usually contain significant amounts of fluorescing species (Mason, 1987). This method is thus suitable as a screening method for the assessment of the state of pollution in a certain area (Ehrhardt & Knap, 1989).

Fluorescence spectroscopy was used for determination of petroleum hydrocarbons in sea water (El Samra *et al.*, 1986; Dujmov & Sucevic, 1989; Ehrhardt & Knap, 1989; Ehrhardt & Petrick, 1989; Ferrer *et al.*, 1998), marine sediments (Badawy *et al.*, 1993; Ehrhardt & Burns, 1993; Al Lihaibi & Al Omran, 1996; Peterson *et al.*, 2001; Gonzales-Macias *et al.*, 2007) and biota (Mason, 1987; Badawy *et al.*, 1993; Ehrhardt & Burns, 1993; Watson *et al.*, 2004; Rodriguez-Sanmartin *et al.*, 2005). Chrysene and crude oil of different origin were most frequently used as standards (Dujmov & Sucevic, 1989; Ehrhardt & Petrick, 1989; Badawy *et al.*, 1993; Rodriguez-Sanmartin *et al.*, 2005), although mixtures of different PAHs were also examined (Mason, 1987; Owen *et al.*, 1995; Peterson *et al.*, 2002). Lately, some new techniques of this method, *e.g.* synchronous fluorescence spectroscopy, have also enabled a better determination of some individual fluorescing compounds (Dissanayake & Galloway, 2004; Hua *et al.*, 2007).

MATERIAL AND METHODS

Study area

The investigated area to the southeast of the Gulf of Trieste is part of the northern Adriatic (Fig. 1). Slovenian coastal area is one of the fast developing regions of Slovenia (Turk & Potočnik, 2001). The number of inhabitants has increased in the last decades and has now reached 80,000 (in the summer period this number may increase five fold). The most important industries in the Slovenian coastal region are metal manufacturing, organic chemicals production and food industry. The agriculture is mostly oriented towards the production of wine, fruit and olive growing, and vegetable cultivation. The Port of Koper has become one of the most important ports in the northern Adriatic and is still increasing its activities. It handles about 10 million tons of cargo per year, among them over 1.5 million tons of oil and oil products and more than 100,000 tons of chemicals. In the studied area, the nautical tourism has also developed with three marinas, in Portorož, Izola and Koper.

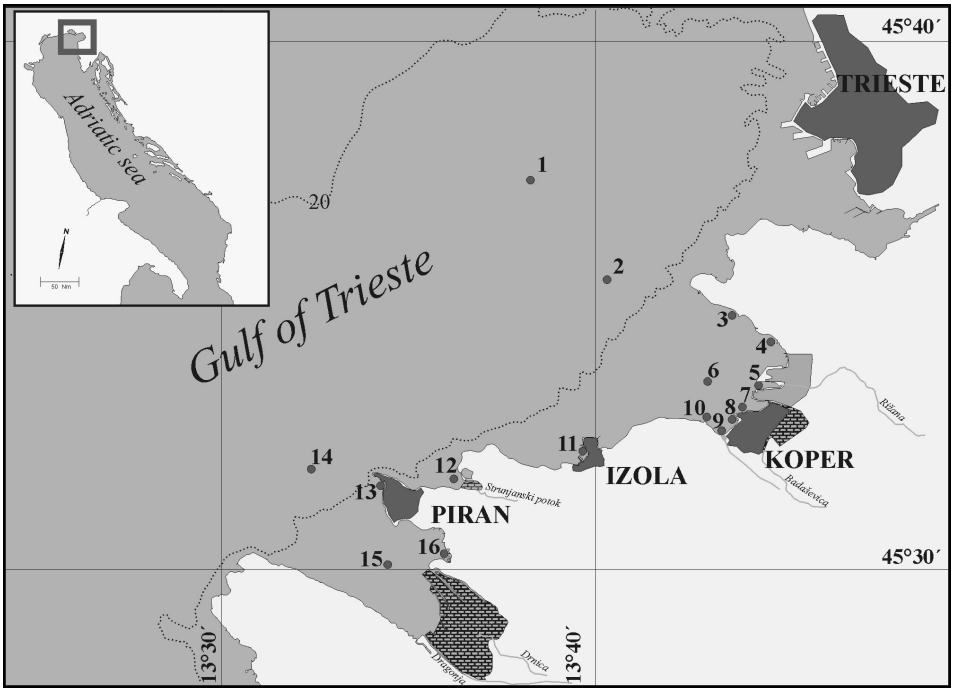

Fig. 1: Sampling sites within the investigated area.
Sl. 1: Vzorčevalna mesta na preiskovanem območju.

One of the severest problems concerning marine environment in this region is sewage discharge. Only two central sewage treatment plants are active in the cities of Koper and Piran, and even there only primary treatment is operating. The sewage from the community of Izola is discharged almost without any treatment. There are also some minor outlets discharging sewage from some smaller towns on the coast. Apart from the above mentioned point sources of pollution, some diffuse sources should also be considered. These are road runoff from the coastal highway, especially significant during the high tourist season, runoff from agricultural areas, river discharges and atmospheric deposition. This area is also affected by pollution sources from other parts of the Gulf of Trieste, sewage discharges from the city of Trieste and intense maritime traffic to the ports of Trieste and Monfalcone (over 30 million tons of oil and oil products per year). A very important source of pollution is the river Isonzo, collecting industrial and municipal wastewaters and discharging them in the northern part of the Gulf of Trieste.

The distribution of sampling sites in Slovenian coastal waters is presented in figure 1. A very short description of sampling sites is given in Table 1. It has to be mentioned that even thought the mussels are very widespread in our sea it was not possible to sample them at all sampling sites.

Experimental

"For residue analyses quality" hexane, methanol and methylene chloride (Fluka) were used for the extraction of hydrocarbons. All other chemicals were of analytical grade, purchased from Merck (Germany). Na_2SO_4 was precleaned by Soxhlet extraction with methanol and hexane and additionally precombusted at 400°C for 6 hours. SiO_2 and Al_2O_3 were precleaned by Soxhlet extraction with methanol and hexane for 8 hours and then dried at 105°C. Before use both oxides were activated at 200°C for 4 hours and then partially deactivated by adding 5% of precleaned water. Cu was activated with HCl and rinsed several times with distilled water, acetone and hexane. It was kept in hexane before used.

Sediment samples were taken by gravity corer. The top 2 cm layer was used for further analyses. Samples were frozen and eventually freezedried. Dry sediment was homogenized. About 10 g of sediment was transferred in a Soxhlet apparatus and extracted for 8 hours with 200 ml of hexane/methylene chloride (1:1). The extracts were dried with Na_2SO_4, concentrated on a rotary evaporator and additionally in a nitrogen stream. Sulphur was removed overnight by the addition of activated Cu. After additional concentration of extracts under nitrogen stream, the partitioning in aliphatic and aromatic fraction was performed on SiO_2/Al_2O_3. Aromatic fraction was concentrated and used for the analyses.

Tab. 1: Short description of the sampling sites.
Tab. 1: Kratek opis vzorčevalnih mest.

Sampling site	Description	Sample
1	Central part of the Gulf of Trieste	Sediment
2	Outer margin of the Bay of Koper	Sediment
3	Northern part of the Bay of Koper	Mussels
4	Small harbour	Mussels
5	Port of Koper	Sediment
6	Central part of the Bay of Koper	Sediment
7	Marina of Koper	Mussels
8	Municipal harbour of Koper	Sediment, mussels
9	Mouth of the river Badaševica	Sediment, mussels
10	Southern part of the Bay of Koper	Mussels
11	Municipal harbour of Izola	Sediment, mussels
12	Strunjan protected area, cultivation of mussels	Sediment, mussels
13	Municipal harbour of Piran	Sediment
14	Outer margin of the Bay of Piran	Sediment
15	Central part of the Bay of Piran	Sediment
16	Marina of Portorož	Sediment

Mussels were sampled manually using a home-made scraper. Each sample was composed of 15 mussels and analyses were performed in 5 parallels. Samples of the whole mussel tissues were homogenized and then freezedried. Dry samples were extracted in a Soxhlet apparatus with 200 ml of methanol for 6 hours. Lipids were saponified by the addition of KOH solution and additionally extracted for 2 hours. Hydrocarbons were extracted with hexane, extracts dried with Na_2SO_4 and concentrated on a rotary evaporator. After additional concentration under nitrogen stream, the hydrocarbons were partitioned in two fractions as already described in the case of sediment samples. Extractable organic matter (EOM) was determined from the mass difference after the evaporation of a certain volume of hexane extracts.

Concentrations of polyaromatic hydrocarbons were determined on a Perkin Elmer LS 30 spectrofluorometer. The excitation and emission wavelengths were 310 nm and 360 nm, respectively. The calculations were made on a chrysene standard basis.

RESULTS AND DISCUSSION

The concentrations of polyaromatic hydrocarbons in marine sediment samples are presented in Table 2. They ranged from 4.2 µg/g to 227.0 µg/g. The highest concentrations were obtained in the municipal harbours of three coastal cities, Koper, Izola and Piran. The water exchange in these areas is very limited and the accumulation of different pollutants is quite important. Higher content of polyaromatic hydrocarbons is an indication of pollution from smaller boats due to exhaust emissions, leaking from engines and reservoirs as well as accidental spillage during the maintenance activities. The harbours are also affected by the runoff from the city streets. The atmospheric deposition seems also not to be negligible, especially in the Izola harbour due to important emissions in the past from the chimney stack of the fish industry. Concentrations in these three harbours are even significantly higher than in the Port of Koper and Marina of Portorož, which are usually thought to be the most polluted areas in the Slovenian sea. Comparison of the polyaromatic hydrocarbons content in the Bay of Koper and Bay of Piran reveals that the latter is less polluted. This area, extended to the area off Piran (sampling site 14), emerges as a rather unpolluted part of the Slovenian sea.

Tab. 2: Concentrations of polyaromatic hydrocarbons in sediment samples (in µg/g dry sediment, chrysene equivalents).
Tab. 2: Koncentracije poliaromatskih ogljikovodikov v vzorcih sedimenta (v µg/g suhega sedimenta, v ekvivalentih krizena).

Sampling site	Concentration (µg/g)
1	17.2
2	8.6
5	18.0
6	14.0
8	49.6
9	9.4
11	68.6
12	17.2
13	227.0
14	4.2
15	6.2
16	13.5

The Bay of Koper is affected by pollution from the Port of Koper. A decreasing gradient is observed from the port to the outer margin of the bay (sites 5, 6 and 2). Concentrations in the central part of the Gulf of Trieste do not follow this gradient, since they are significantly higher. This is most probably due to the influence of the city of Trieste (including sewage discharge) and intensive maritime traffic to the Port of Trieste. The rather high concentrations of polyaromatic hydrocarbons at sampling site 12 (Strunjan Bay) were surprisingly higher than expected. This area is a protected area and it was usually used as a reference site. The results of this study revealed comparable polyaromatic hydrocarbons content to those in the Port of Koper and central part of the Bay of Koper. In the case of the Port of Koper, however, the dredging activities can affect the content of different pollutants in marine sediments and direct comparison could sometimes be difficult. One of the possible sources of pollution with hydrocarbons at sampling site 12 could be a small stream, which is bringing runoff waters from the crossroad on the main coastal road to Croatia.

The second part of the work comprised the analyses of polyaromatic hydrocarbons in mussel samples collected along the Slovenian coast. Mussels are usually used for this purpose, since they accumulate pollutants in their tissue. General characteristics of the mussel samples are presented in Table 3. Some of these characteristics are usually used as "normalization factors" for better comparison of results, since the accumulation of pollutants is also time dependant. The content of pollutants in different environmental samples is significantly dependant on the conditions in the environment. This is the reason why the extractable organic matter was used to normalize the results (Gonzales-Macias *et al.*, 2007).

The highest concentration of polyaromatic hydrocarbons in mussel tissue was obtained at sampling site 11 in the Bay of Izola. This is in accordance with high polyaromatic hydrocarbons content obtained in sediments at the same sampling site. Much lower, but still elevated concentrations were obtained in the marina and municipal harbour of Koper. Concentrations at other sampling sites in the Bay of Koper were rather low, except those at site 4, situated in a small harbour at Sv. Katarina, an area with important sea-grass meadow of *Cymodocea nodosa*. This area is close to the Port of Koper and as such affected by port activities and maritime traffic. Elevated concentrations of polyaromatic hydrocarbons in sediments at sampling site 12 are not reflected in a higher amount in mussel sample. This area is used for mussel cultivation and the time of accumulation of pollutants is most probably shorter. This could also be an important observation, taking into account human health.

As previously mentioned, the different time of accumulation of pollutants, *e.g.* different mussel age, can affect the interpretation of the results and may lead to incorrect conclusions. For this reason the concentrations of polyaromatic hydrocarbons in mussel samples were expressed on the amount of extractable organic matter (Fig. 2). The distribution pattern remained very similar, while the difference in concentrations between sampling sites 4, 7 and 8 became less significant (Tab. 4).

There are not many results in the literature about the hydrocarbons pollution of sediments or biota assessment using fluorescence spectroscopy. Some authors (Gonzales-Macias *et al.*, 2007) established the background concentration of total aromatic hydrocarbons in sediments of the Mexican Salina Cruz Bay at 5µg/g. The highest concentrations in this area exceeded 2000 µg/g. In the Arabian Gulf, the concentrations up to 90 µg/g were related to moderate chronic pollution, while the content in heavily polluted areas reached 1448 µg/g (Massoud *et al.*, 1996). Concentrations in surface sediments of the Black Sea were in the range from 2 µg/g to 310 µg/g and could be comparable to those encountered in the Mediterranean (Readman *et al.*, 2002). Some fairly old results for the Mediterranean (Mille *et al.*, 1982; Barnier *et al.*, 1986) confirm this established range of concentrations in sediment samples. Concentrations in sediments from the open Adriatic Sea were below 1 µg/g (Dujmov & Sučević, 1989). Some authors (Bajt, 2000; Notar & Leskovšek, 2000; Notar *et al.*, 2001) presented some results of the analyses of polyaromatic hydrocar-

Tab. 3: Characteristics of mussel samples.
Tab. 3: Značilnosti vzorcev školjk.

Sampling site	Length (cm)	STD	Width (cm)	STD	Weight, wet (g)	STD	EOM (mg/g)
3	5.7	0.1	2.7	0.1	4.1	0.3	143
4	5.2	0.2	2.9	0.2	3.8	0.3	150
7	5.0	0.2	2.6	0.2	2.4	0.3	236
8	5.9	0.1	2.7	0.1	1.8	0.2	180
9	5.4	0.1	2.9	0.1	4.2	0.6	194
10	4.6	0.2	2.4	0.2	2.9	0.6	148
11	4.5	0.1	2.3	0.1	1.8	0.2	125
12	6.9	0.1	3.4	0.1	4.8	0.4	207

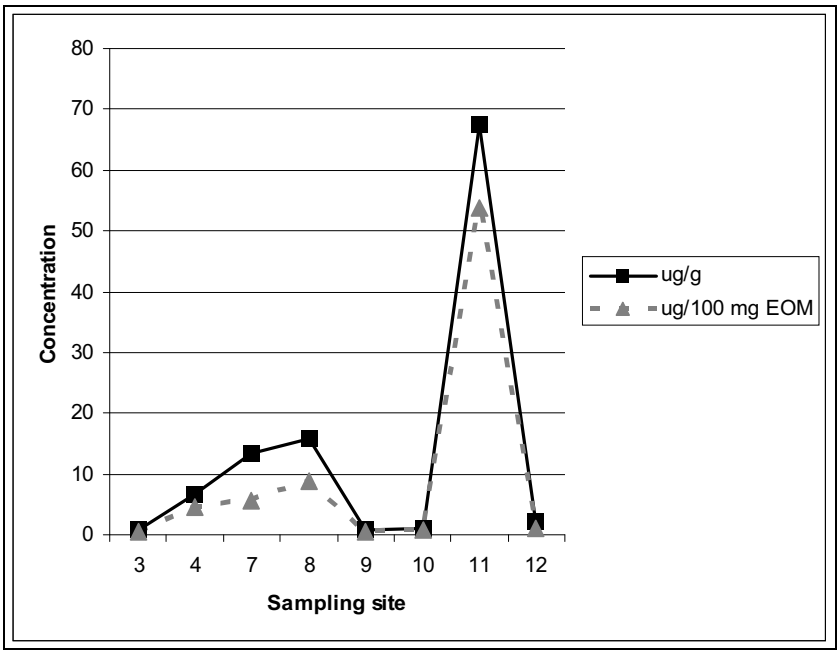

Fig. 2: Concentrations of polyaromatic hydrocarbons in mussel tissue normalized on EOM.
Sl. 2: Koncentracije poliaromatskih ogljikovodikov v tkivu školjk, normalizirane na EOS.

bons (PAH) in sediment samples and mussel samples from the Gulf of Trieste. These analyses were performed by gas chromatography. Unfortunately, the direct comparison of these results is not possible. The content obtained by fluorescence spectroscopy is usually higher, considering that it also includes degradation products and other fluorescing polyaromatic hydrocarbons.

Tab. 4: Content of polyaromatic hydrocarbons in mussel samples (in µg/g dry weight, chrysene equivalents).
Tab. 4: Vsebnost poliaromatskih ogljikovodikov v vzorcih školjk (v µg/g suhe teže, v ekvivalentih krizena).

Sampling site	Concentration (µg/g)	STD
3	0.8	0.1
4	6.7	1.6
7	13.4	3.1
8	15.9	0.8
9	0.9	0.1
10	1.0	0.1
11	67.3	7.1
12	2.2	0.3

Fluorescence spectroscopy was used for the analyses of biota samples as well. Concentrations below 1 µg/g (wet weight) of hydrocarbons in farmed mussels *Mytilus galloprovincialis* from Galicia (Spain) were detected (Rodriguez-Sanmartin *et al.*, 2005).

Comparison of the results obtained in the present study with the above presented results from the literature leads to the conclusion that Slovenian sea is, in general, only moderately polluted with polyaromatic hydrocarbons. There are some areas (harbours, marinas) with elevated content of polyaromatic hydrocarbons due to the limited exchange of seawater and consequently higher accumulation.

CONCLUSIONS

The fluorescence spectroscopy was used for the assessment of the state of Slovenian sea in terms of the pollution with polyaromatic hydrocarbons. The results of the analyses of sediment and mussel samples showed elevated concentrations of polyaromatic hydrocarbons in municipal harbours of the three Slovenian coastal cities, as well as in marinas along the coast. The Bay of Koper is more polluted in comparison to the Bay of Piran, which could be considered a less polluted area of the Slovenian coastal waters. The Bay of Koper is affected by port activities and maritime traffic. In the central part of the Gulf of Trieste, a certain influence of the city of Trieste with its port and maritime traffic was observed. In general, Slovenian coastal sea may be considered moderately polluted with polyaromatic hydrocarbons.

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OCENA ONESNAŽENJA SLOVENSKEGA MORJA S POLICIKLIČNIMI AROMATSKIMI OGLJIKOVODIKI

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POVZETEK

V članku je predstavljena ocena onesnaženosti slovenskega morja z vidika vsebnosti poliaromatskih ogljikovodikov v vzorcih sedimenta in školjk. V ta namen je bila uporabljena fluorescenčna spektroskopija. Povišane koncentracije poliaromatskih ogljikovodikov smo zasledili v komunalnih mandračih treh slovenskih obalnih mest in tudi v marinah vzdolž obale. Koprski zaliv je bolj onesnažen v primerjavi s Piranskim zalivom, ki je videti tudi kot najmanj onesnaženo območje slovenskega obalnega morja. Koprski zaliv je pod vplivom pristanišča in pomorskega prometa. V osrednjem delu Tržaškega zaliva je opazen tudi vpliv mesta Trst s pristaniščem in pomorskim prometom. V glavnem lahko zaključimo, da je slovensko morje le zmerno onesnaženo s poliaromatskimi ogljikovodiki.

Ključne besede: poliaromatski ogljikovodiki, onesnaženje, sedimenti, školjke, fluorescenčna spektroskopija, slovensko morje

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L'INTRODUZIONE IN EUROPA DI *TAPES PHILIPPINARUM* (ADAMS & REEVE, 1852), LA VONGOLA VERACE FILIPPINA

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SINTESI

Assieme a Crassostrea gigas*, l'ostrica giapponese,* Tapes philippinarum *è la più importante specie di mollusco alloctono introdotta ed adattata alle acque europee, tanto da dare produzioni annuali valutabili in 50.000 t circa nel 2005. Specie di origine indopacifica, originaria della zona compresa tra le isole del Giappone, la Nuova Guinea e la costa orientale dell'India, è stata importata negli USA e nel Canada a partire dagli anni '30. E' stata immessa in Europa nel corso del 1970 assieme a* C. gigas *dopo le morie di ostriche piatte,* Ostrea edulis*, verificatesi sulle coste francesi. La riproduzione controllata è stata messa a punto nei laboratori americani ed ha incominciato ad essere replicata in Europa da ricercatori inglesi, francesi, spagnoli ed italiani. Introdotta nella Laguna di Venezia nel 1983, la specie si è poi diffusa in Italia ed ha dato origine a notevoli produzioni provenienti tanto dalla pesca quanto dall'acquacoltura.*

Parole chiave: *Tapes philippinarum*, specie alloctone, allevamento, UE

ABOUT THE INTRODUCTION OF MANILA CLAM *TAPES PHILIPPINARUM* (ADAMS & REEVE, 1852) INTO EUROPE

ABSTRACT

Together with the Japanese oyster, Crassostrea gigas, Tapes philippinarum *is the most important species of exotic clam that successfully adapted to European waters. Of Indo-Pacific origins, it was first imported in the USA and Canada in the 1930s and introduced in Europe in the 1970s together with* C. gigas *after the large-scale mortality of flat oysters,* Ostrea edulis*, which occurred along the French coasts. Controlled reproduction was developed in American laboratories and was then exported to Europe by English, French, Spanish and Italian researchers. Juvenile samples of English production were introduced into the Venice lagoon in 1983. The species was then diffused throughout Italy, resulting in considerable production from both harvesting wild products and aquaculture. On the basis of these historical and economic premises, the European Union has decided to naturalize the presence of* T. philippinarum *on a par with other species with similar backgrounds.*

Key words: *Tapes philippinarum*, exotic species, breeding, UE

INTRODUZIONE

Quasi fino alla fine del 1800, le caratteristiche biogeografiche del Mediterraneo erano il risultato dell'equilibrio tra una componente "endemica", formatasi alla fine del Terziario e variamente rappresentata nei diversi gruppi vegetali e animali (ad es. *Posidonia oceanica, Corallium rubrum*...) e una componente "atlanto-mediterranea" pressochè stabile nel corso del Quaternario (ad es. *Pecten jacobaeus, Cardium tuberculatum*...). L'assetto era completato da limitati apporti "boreo-atlantici" e "senegalesi" verificatisi ad ondate successive attraverso Gibilterra nel corso dei periodi glaciali ed interglaciali, rispettivamente (Pérès & Picard, 1964). Queste componenti e piccole rappresentanze "cosmopolite" e "circumtropicali" hanno connotato la biogeografia del Mediterraneo fino al XIX secolo. Questo assetto originario, conservatosi per migliaia di anni, è andato via via alterandosi a partire dalla fine del 1800 con l'apertura del Canale di Suez (1869) e quindi con lo stabilirsi di contatti permanenti con l'oceano indopacifico, con l'incremento dei traffici marittimi e con lo stabilirsi di altre forme di scambio intercontinentale quali la maricoltura e l'aquariologia soprattutto.

Le influenze indopacifiche attraverso Suez non sono state avvertite immediatamente ma via via che si attenuava la barriera alina rappresentata dai Laghi Amari, le "specie lessepsiane" hanno incrementato i loro passaggi e nel 1978 si pensava che la componente indopacifica introdotta per questa via assommasse a circa 200 specie (Dov Por, 1978). Alcune di esse come *Halophila stipulacea* e *Brachidontes variabilis* sono ormai stabilmente insediate sulla costa orientale della Sicilia. Altre specie della stessa origine come *Caulerpa taxifolia* sono state invece introdotte attraverso pratiche acquariologiche o come *Scapharca inaequivalvis* attraverso traffici navali (Rinaldi, 1972).

L'aumentato deficit idrico del Mediterraneo, conseguente all'attuale fase climatica, ha inoltre incrementato l'ingresso di specie atlantiche temperato calde che si insediano soprattutto lungo le coste meridionali del bacino.

In riferimento all'arrivo ed alla diffusione di specie alloctone utilizzate per pratiche di acquacoltura o di ripopolamento, Leppäkoski *et al.* (2002) individuano 69 specie esotiche introdotte in Europa dalla fine del XIX secolo: 28 molluschi bivalvi, 27 pesci, 10 alghe, 3 gasteropodi e una pianta da fiori. Due di queste, la trota iridea *(Oncorhynchus mykiss)* e l'ostrica giapponese *(Crassostrea gigas),* figurano attualmente tra le principali specie acquicole europee. Secondo stime recenti, l'ostrica giapponese rappresenta oggi l'80% della produzione mondiale di ostriche.

Anche l'introduzione di *Tapes philippinarum* ha seguito un simile sviluppo produttivo all'interno della Comunità Europea.

TAPES PHILIPPINARUM IN EUROPA

Fin dalla sua importazione in Nord America, a partire dagli Anni '30 (Anderson *et al.*, 1982), *Tapes philippinarum* è oggetto di riproduzione controllata in strutture denominate schiuditoio (in italiano), *hatchery* (in inglese) ed *ecloserie* (in francese). Questa specie riveste inoltre un fondamentale ruolo nell'economia alieutica, visti la pesca e l'allevamento che vengono praticati in diversi stati del Vecchio Continente (Francia, Spagna, Inghilterra, Irlanda, Italia...). La specie è inoltre oggetto di grossa attenzione ed è richiesta sia per l'allevamento che per il consumo anche in altre nazioni costiere, in particolare sulla sponda orientale dell'Adriatico.

T. philippinarum proviene dal Pacifico e, in relazione alla sua origine esotica, gli anglosassoni la chiamano Manila clam. La specie è stata introdotta nella West Coast degli Stati Uniti dal Giappone attraverso le importazioni di giovanili di un'altra specie esotica, *Crassostrea gigas* (Pacific oyster) nei lontani anni '30 e '40 del '900 (Anderson *et al.*, 1982).

La "comparsa" di *T. philippinarum* in Europa viene fatta risalire al 1972. Questa data è segnalata nell'articolo "Clam Culture in France: A private and public sector Partnership" (Flassch, 1992). Nelle prime righe dell'articolo citato si legge: *"Clam culture was established in France with the production of a species imported from the Pacific in 1972, Tapes philippinarum. The development of the fledgling industry followed a series of steps, from research to a strategic breeding program".*

Lucas (1977) illustra lo stato della pesca della vongola verace europea *(Tapes decussatus)* ed il nuovo prodotto disponibile con la produzione artificiale di seme in schiuditoio. Lo stesso Lucas *(ibid.)* riporta però che, nell'anno 1976, solo 3 schiuditoi erano stati capaci di vendere del seme di vongola motivando lo scarso risultato commerciale con ragioni sia di tipo tecnico che per l'instabilità del mercato del seme.

I tre schiuditoi citati dall'autore erano:

"L'écloserie de la Seasalter Shellfish Ltd à Whitsable (Angleterre), créée en 1966, produit du naissain de l'espèce européenne. Selon le directeur technique (John Bayes), 20 millions de palourdes ont été produites en 1974, mais seulement 1 million de palourdes ont été vendues".

"L'International Shellfish Entreprises Inc, installée depuis 1977 à Moss Landing, en Californie (U.S.A.), commercialise surtout le naissain d'huitres. Sa production de naissain de palourde japonaise demeure, jusqu'à présent, plus irrégulière, bien que des lots important saint été exportés en France.

"L'écloserie de la Société Atlantique de Mariculture (Satmar), créée en 1971 et située a Barfleur (Manche), produit, depuis 1974, du naissain des deux espèces de

palourdes, mais seule la production de la japonaise est intensive et régulière. Selon les indications de M. Yves Le Borgne, directeur technique, 10 millions de palourdes ont été produites en 1976 et 2 millions ont été vendues".

Da questo articolo del 1977 appare evidente che le riproduzioni e le introduzioni di giovani vongole filippine in Francia erano già avvenute almeno dal 1974.

Queste attività di venericoltura in Francia hanno seguito un piano di sviluppo nazionale a carattere pubblico/privato. La descrizione del piano viene riportata anche da Flassh (1987), che così descrive le diverse fasi:

"Quatre phases de prédéveloppement se son succédées:

1975–1978: faisabilité scientifique et technique.

1979–1984: programmes régionaux:

Nord Finistère (CNEXO) – Sud Finistère (ISTPM) – Charente-Maritime (Délégation Régionale à l'aquaculture et CCI de Rochefort) – Vendée (organismes scientifiques et SMIDAP).

1981–1984: programme national palourdes. 6,8 millions de bétes, un financement de 456.000 FRF (ANVAR-CNEXO)... Il a abouti à production de plus de 17 tonnes de palourdes, engendrant un C.A. de 654.000 FRF.

1985–1986: programme expérimental "stratégie d'élevage. Financé par IFREMER (733.000 FRF) et les Régions Poitou-Charentes et Aquitaine (195.000 FRF); production 18 tonnes, C.A. 920.000 FRF".

In Italia, il seme di vongola verace filippina è arrivato per la prima volta nell'anno 1983. I giovani di *T. philippinarum*, in ragione di 200.000 esemplari, sono stati importati dall'Inghilterra e seminati nella Laguna di Venezia, vicino a Chioggia (Breber, 1985). Lo stesso autore nel suo libro del 1996 conferma: *"sapevo allora, alla fine degli anni '70, che l'acquacoltura della filippina, specie molto simile alla nostrana sotto tutti i punti di vista, era in alcuni paesi abbastanza consolidata..."* (Breber, 1996).

Le introduzioni sono continuate poi nella Sacca degli Scardovari (Milia, 1990) e in Sardegna nel 1985 (Cottiglia & Masala Tagliasacchi, 1988), nella Laguna di Marano e Grado (Zentilin, 1987) e nella Sacca di Goro nel 1986 (Paesanti, 1990), e nel Lago di Sabaudia nel 1989 (Di Marco *et al.*, 1990).

Si deve convenire che ormai anche in Italia, questa specie fa parte, assieme ad altre specie alloctone, del patrimonio produttivo ed economico, con produzioni nazionali che variano dalle 62.000 t/anno del 1999 (Paesanti & Pellizzato, 2000) alle circa 25.000–30.000 t/anno (fonte ANSA, 2003) ed alle 50.000 t/anno del

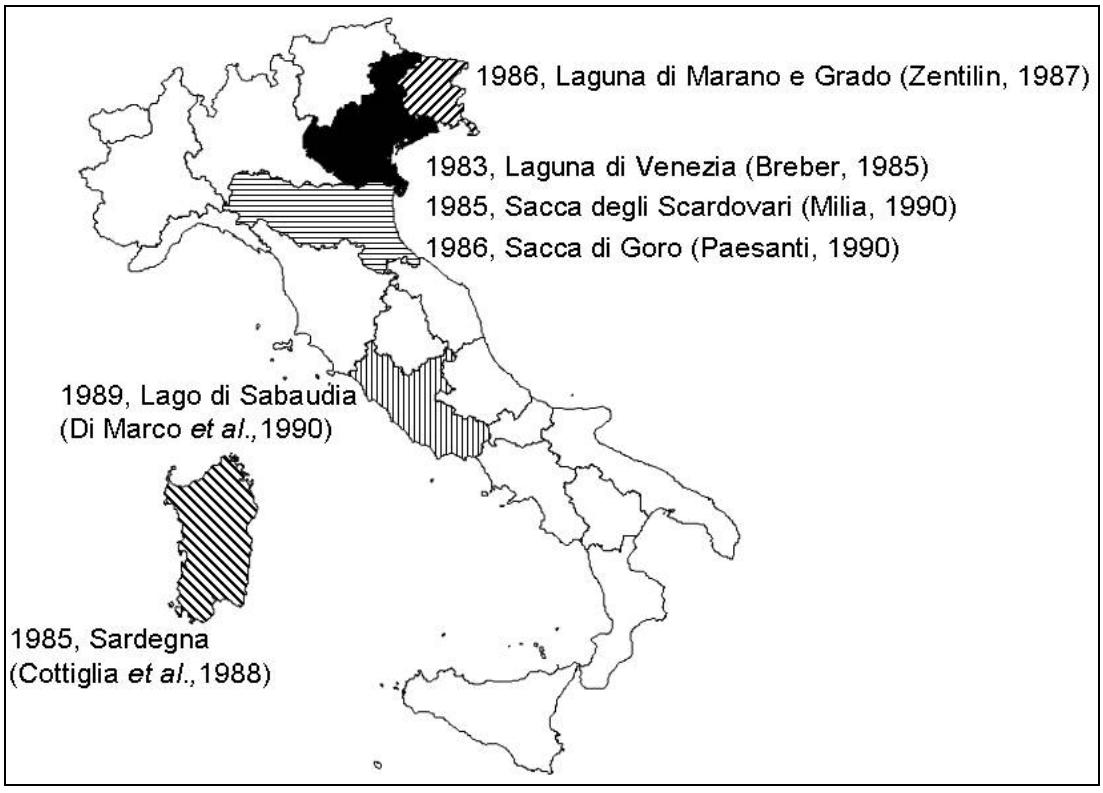

Fig. 1: L'introduzione della vongola verace *Tapes philippinarum* ***(Adams & Reeve, 1850) in Italia.***
Sl. 1: Naselitev filipinske vongole *Tapes philippinarum* ***(Adams & Reeve, 1850) v Italijo.***

2005 (stime personali) provenienti principalmente dalle regioni dell'Alto Adriatico (Friuli Venezia Giulia, Veneto, Emilia Romagna). In analogia con gli altri stati d'Europa, il suo sviluppo, è stato supportato con diversi contributi pubblici sia nazionali che regionali.

E' utile infine fornire un ulteriore dato. Nel suo rapporto: "La PCP in cifre. Dati essenziali sulla politica comune della pesca. Edizione 2006" (http://ec.europa.eu/fisheries), la UE individua la specie "Vongola verace" fra le 10 specie più allevate in acquacoltura dell'Unione Europea (2003) ponendola al nono posto con un totale pari a 27.411 t, derivante prevalentemente dalla produzione italiana (Osservatorio Socio Economico della Pesca dell'Alto Adriatico, 2006).

In conclusione, l'origine geologica terziaria, l'evoluzione quaternaria, la storia recente, le vicissitudini climatiche attuali (Bianchi, 2007) e gli scambi commerciali fanno del Mediterraneo un naturale incrocio di faune e di flore di differente provenienza. L'influenza dei vecchi e dei nuovi meccanismi d'ingresso deve essere attentamente monitorata soprattutto per accumulare conoscenze atte ad accogliere o respingere nuove proposte d'introduzione di specie alloctone, prendendo tuttavia atto che molte delle attuali produzioni della maricoltura europea si basano su alcune di esse.

In molti casi, i movimenti di specie non indigene, sono stati infatti responsabili della diffusione di altre specie non desiderate tra cui parassiti ed infestanti (ad esempio, insieme alle ostriche sono stati introdotti organismi quali *Crepidula fornicata* e *Styela clava)*. Una prudente ed attenta politica sulle nuove introduzioni a scopo commerciale è perciò necessaria per minimizzare questi pericoli permettendo nel contempo lo sviluppo di nuove pratiche di maricoltura con specie di accertata affidabilità ecologica.

Sulla base dei riferimenti forniti e discussi, è possibile perciò affermare che *T. philippinarum* è una specie già saldamente inserita nell'acquacoltura europea da più di 30 anni e che la sua diffusione in diversi ambienti paralici del continente ha ampiamente dimostrato di non costituire un pericolo per gli ecosistemi originari, rappresentando nel contempo una notevole fonte reddituale (Orel *et al.*, 2005). Le attività connesse alla sua coltura dovrebbero pertanto beneficiare di un trattamento che ne agevoli lo sviluppo.

NOTA FINALE

Recentemente è stato emanato il Regolamento (CE) n. 708/2007 del Consiglio della Comunità Europea dell'11 giugno 2007 relativo all'impiego in acquacoltura di specie esotiche e di specie localmente assenti. Nell' articolo 2, paragrafo 5 si legge: *"Il presente regolamento, ad eccezione degli articoli 3 e 4, non si applica alle specie elencate nell'allegato IV. La valutazione del rischio di cui all'articolo 9 non si applica alle specie elencate nell'allegato IV, salvo qualora gli Stati membri desiderino limitare l'impiego nel loro territorio delle specie interessate"*.

L'allegato IV riporta: Elenco delle specie di cui all'articolo 2, paragrafo 5:

Trota iridea, *Oncorhynchus mykiss*
Salmerino di fonte, *Salvelinus fontinalis*
Carpa, *Cyprinus carpio*
Carpa erbivora, *Ctenopharyntgodon idella*
Carpa argentata, *Hypophthalmichthys molitrix*
Carpa testa grossa, *Aristichtys nobilis*
Ostrica giapponese, *Crassostrea gigas*
Vongola verace, *Ruditapes philippinarum*
Persico trota, *Micropterus salmoides*
Salmerino alpino, *Salvelinus alpinus*

Fig. 2: Cartolina storica: la raccolta di molluschi bivalvi a Marano Lagunare nei tempi antichi.
Sl. 2: Zgodovinska razglednica: nabiranje školjk v Maranski laguni (Italija) v preteklosti.

NASELITEV FILIPINSKE VONGOLE *TAPES PHILIPPINARUM* (ADAMS & REEVE, 1852) V EVROPO

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POVZETEK

*Filipinska vongola (*Tapes philippinarum*) je skupaj z japonsko ostrigo (*Crassostrea gigas*) najpomembnejša alohtona vrsta mehkužcev, ki je bila prinesena v Evropo in se je dobro prilagodila razmeram v evropskih vodah. Letna produkcija je leta 2005 znašala približno 50.000 t. Vrsta je indo-pacifiškega izvora, prihaja iz območja med japonskim otočjem, Novo Gvinejo in vzhodno obalo Indije. V ZDA in Kanado je bila naseljena v tridesetih letih prejšnjega stoletja, v Evropo pa okoli leta 1970, skupaj s* C. gigas*, po množičnih poginih užitne klapavice* (Ostrea edulis) *na francoski obali. V ameriških laboratorijih so uvedli nadzor nad njenim razmnoževanjem, kar so v Evropi ponovili angleški, francoski, španski in italijanski raziskovalci. Filipinsko vongolo so naselili v beneško laguno leta 1983. Vrsta se je nato razširila po Italiji in njena visoka produkcija izvira tako iz nabiranja gojenih školjk kot vongol iz naravnih rastišč.*

Ključne besede: *Tapes philippinarum*, alohtone vrste, gojenje, EU

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QUANTIFICATION OF WING PIGMENTATION AND IDENTIFICATION OF PIGMENTS IN WINGS OF *PALPARES LIBELLULOIDES* (LINNAEUS, 1764) (NEUROPTERA: MYRMELEONTIDAE)

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ABSTRACT

Pigmentation of the wings in Palpares libelluloides *was quantified with light absorbance at specific wavelengths. Absorption of yellow parts of the wings in females was higher than in males. In the yellow parts of the wings, the pigments sepiapterin and xanthopterin were identified, whereas in their black spots the melanin was present.*

Key words: Neuroptera, Myrmeleontidae, *Palpares libelluloides*, wings, coloration, pigments

QUANTIFICAZIONE DI PIGMENTAZIONE DI ALI ED IDENTIFICAZIONE DI PIGMENTI IN ALI DI *PALPARES LIBELLULOIDES* (LINNAEUS, 1764) (NEUROPTERA: MYRMELEONTIDAE)

SINTESI

La pigmentazione delle ali di Palpares libelluloides *è stata quantificata con l'assorbanza della luce a specifiche lunghezze d'onda. L'assorbimento delle parti gialle delle ali è risultato maggiore nelle femmine che nei maschi. Nelle parti gialle delle ali sono stati identificati i pigmenti sepiapterina e xantopterina, mentre nelle macchie nere era presente la melanina.*

Parole chiave: Neuroptera, Myrmeleontidae, *Palpares libelluloides*, ali, colorazione, pigmenti

INTRODUCTION

Palpares libelluloides (Linnaeus) occurs as a single species from the tribe Palparini in Europe (Mansell, 1990). It is widely distributed in the Mediterranean reaching Iran and Caucasus (Aspöck *et al.*, 1980). In Slovenia, the species has not yet been found (Devetak, 1996), although it is expected. As predator on insects and spiders, it inhabits grassland areas and scrub communities. Macroscopically, its pale yellow wings with black spots do not substantially differ between males and females and seem to have more mimic than warning appearance. A similar coloration of wings with yellow pigments pteridines (sepiapterin and xanthopterin) and black melanin was reported for *Libelloides macaronius* (Senčič, 2006). The same pigments were detected in the integument of a scorpion fly *Panorpa japonica* (Nakagoshi *et al.*, 1984). Yellow pigments in insects could also be ommochromes, porfirines or compounds originating from food ingested, like carotenoides and flavones (Peters, 1999).

In the present study, the intensity of pigmentation of the wings was measured with absorption of the light. The pigments were extracted from the wings and identified.

MATERIAL AND METHODS

Adult specimens of *Palpares libelluloides* (Linnaeus) were collected in grasslands near the village of Nerezine (44°40′ N, 14°24′ E) on the island of Lošinj in Croatia (Fig. 1) and stored at –25°C before use. Intensity of coloration of the wings was measured according to the method described in an earlier paper (Senčič, 2006). Briefly, from each right hind wing (from 10 males and 10 females) about 2 cm long distal part was cut off and clumped between two plates with a 1.9 mm aperture. This holder was inserted on the front of the sample chamber in spectrophotometer (Perkin-Elmer, Lambda 11/Bio). Absorption was measured in parts with intensive and homogenous pigmentation (Fig. 2). The yellow parts were measured at 425 nm wavelength (at the absorption maximum of pteridines (Stark, 1974; Nakagoshi *et al.*, 1984)) and black spots at 650 nm wavelength (as recommended for quantification of melanin (Virador *et al.*, 1999)). The data were statistically analysed with Student's *t* test, the correlation coefficient *r* and *F* test; all tests were performed with the computer package STATISTICA (StatSoft, Inc.).

Identification of melanin was performed by soaking the black part of the wing in the solution of the methylene blue (7 mg l^{-1}) in KCl buffer (0.2 mol l^{-1}), pH = 1 (Lillie, 1954).

Extraction and analysis of the yellow pigments were performed from 6 fore and 6 hind wings. The wings were separated in yellow (93.8 mg) and black parts (9.0 mg) in two mortars. After grinding with 42 mg of quartz sand for 5 min, the extraction was performed with 600 and 300 µl of 0.4% sucrose, respectively, in a dim light. After 10 min of centrifugation at 1000 g, the reextraction of each pellet was performed with 250 µl of 0.4% sucrose. The absorption spectra of pooled supernatants

Fig. 1: A pasture near Nerezine (Lošinj), July 1992. (Photo: D. Devetak)
Sl. 1: Pašnik blizu Nerezin (Lošinj), julij 1992. (Foto D. Devetak)

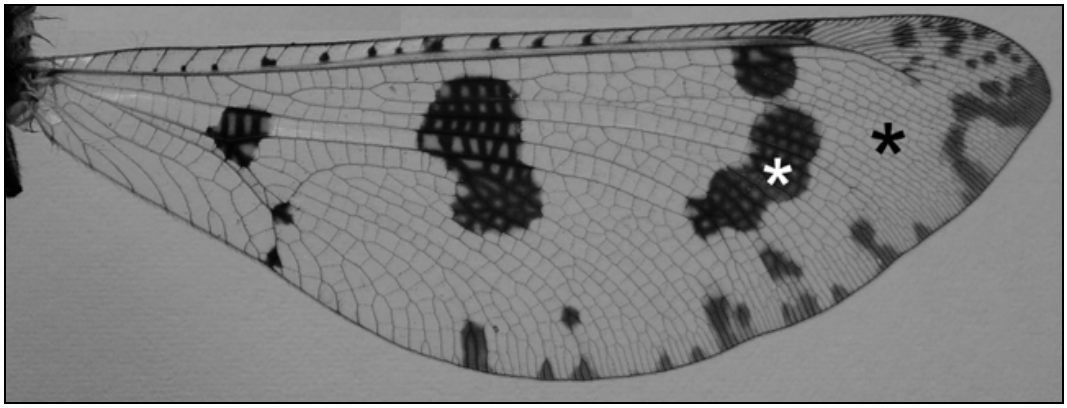

Fig. 2: Hind wing of ant-lion** Palpares libelluloides**. Black and white asterisks indicate the points where absorption was measured. Length of the hind wing is 55 mm.
Sl. 2: Zadnje krilo volkca vrste** Palpares libelluloides**. Črna in bela zvezdica kažeta mesti, kjer je bila merjena absorpcija. Dolžina zadnjega krila je 55 mm.

were scanned at 350-700 nm. The freeze-dried supernatants (0.5 mg of each) were dissolved in 3 µl of deaerated water and applied (3 × 0.5 µl) on aluminium sheet with Silica gel 60 F_{254} (6 × 20 cm; Merck, Germany). The marker (0.1 mg in 1µl) was sepiapterin (Schircks, Switzerland). The paper chromatography (with paper MN214, Macherey-Düren, Germany) was performed under the same conditions, except that a double amount of samples was applied.

RESULTS

Both in males and females the yellow parts of the wings absorbed the light at 425 nm wavelength less intensively than black parts at 650 nm (Tab. 1), but absorption of the yellow parts in females was significantly higher than in males, $F_{1.18} = 4.43$ at $p = 0.049$. In absorption of the black parts of the wings, there was no difference between males and females, $F_{1.18} = 0.13$ at $p = 0.726$. The ratio "absorption of the yellow part of the wing at 425 nm / absorption of the black part of the wing at 650 nm" varied individually (data not shown). No correlation between these two parameters was obtained in males ($r = 0.29$, $p = 0.412$) nor in females ($r = 0.27$, $p = 0.449$).

In the wings' black parts, the presence of the black pigment melanin was confirmed. After reaction of the dark parts of the cut wings with methylene blue at pH 1, a dark green coloured margin appeared.

From the yellow as well as black parts of the wings, yellow extracts with the absorption maximum at 420–425 nm (characteristic for pteridines) were obtained. Absorptions of light at 425 nm wavelength of the first extracts were 0.557 and 0.221, and 0.428 and 0.172, of the second extracts. According to the calculations from this data, the concentration of the yellow pigments is 8.3 times higher in black spots than in the yellow parts of the wings.

Tab. 1: Intensity of pigmentation of the wings of** P. libelluloides**, expressed as absorption of the light. Yellow parts were measured at 425 nm and black parts at 650 nm. Values are means ± standard deviation, N = 10, * = p<0.05.
Tab. 1: Intenziteta obarvanosti kril pri volkcu vrste** P. libelluloides**, izražena z absorpcijo svetlobe. Njegovi rumeni deli so bili merjeni pri valovni dolžini 425 nm, črni pa pri 650 nm. Vrednosti so podane kot srednje vrednosti ± standardni odklon, N = 10, * = p<0.05.

Gender	Absorption of the yellow parts of wings at 425 nm	Absorption of the black parts of wings at 650 nm
Males	0.537 ± 0.143	0.818 ± 0.119
Females	0.681 ± 0.136*	0.834 ± 0.115

Identification of the pigments with thin-layer chromatography revealed the presence of two yellow spots with Rf 0.35 and 0.56 in both extracts (Fig. 3). The first spot was not identified, while the second corresponded to the marker sepiapterin. In both extracts, two yellow pigments were also identified after paper chromatography (Fig. 4). The first pigment with Rf 0.27 was after comparing the Rf values (Hama *et al.*, 1965) identified as xanthopterin, while the second with Rf 0.44 corresponded to the marker sepiapterin.

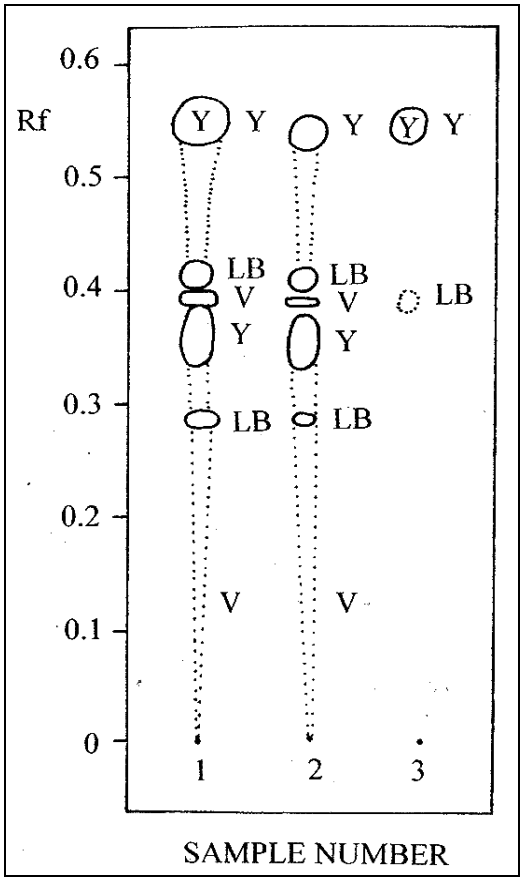

Fig. 3: Thin-layer chromatography of the extracts from the wings of ant-lion *P. libelluloides*. ***Samples: 1 – from yellow parts, 2 – from black parts, 3 – pure sepiapterin. Yellow spots visible at daily light are indicated with Y in the centre of the spot. On the right side, the colour of fluorescence at 365 nm is indicated: LB – light blue, V – violet, Y – yellow.***

Sl. 3: Tankoplastna kromatografija ekstraktov kril volkca vrste *P. libelluloides*. ***Vzorci: 1 – od rumenih delov, 2 – od črnih lis, 3 – čisti sepiapterin. Rumene lise, ki so vidne pri dnevni svetlobi, so označene z Y v sredini lise. Na desni strani so označene barve fluorescence pri 365 nm: LB – svetlo modra, V – vijolična, Y – rumena.***

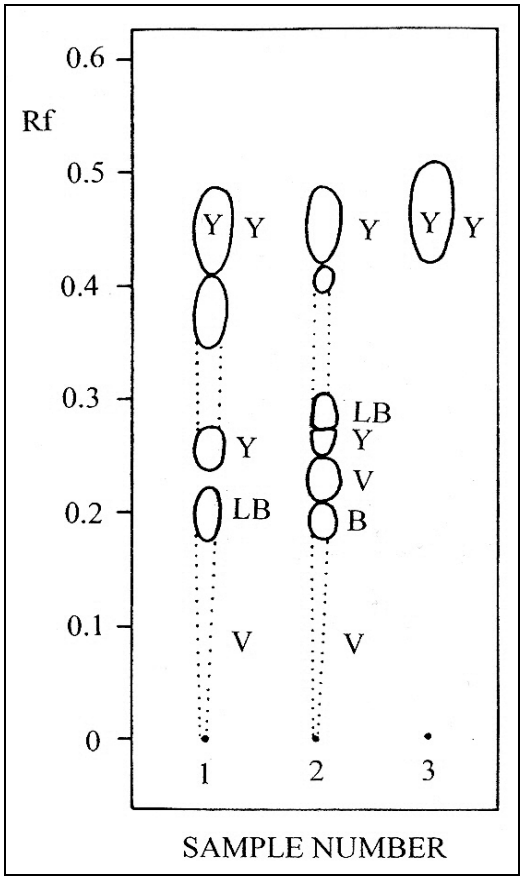

Fig. 4: Paper chromatography of the extracts from wings of the ant-lion *P. libelluloides*. ***Samples: 1 – from yellow parts, 2 – from black parts, 3 – pure sepiapterin. Yellow spots visible at daily light are indicated with Y in the centre of the spot. On the right side, the colour of fluorescence at 365 nm is indicated: B – blue, LB – light blue, V – violet, Y – yellow.***

Sl. 4: Papirna kromatografija ekstraktov kril volkca vrste *P. libelluloides*. ***Vzorci: 1 – od rumenih delov, 2 – od črnih lis, 3 – čisti sepiapterin. Rumene lise, ki so vidne pri dnevni svetlobi, so označene z Y v sredini lise. Na desni strani so označene barve fluorescence pri 365 nm: B – modra, LB – svetlo modra, V – vijolična, Y – rumena.***

DISCUSSION

The pale yellow wings of *Palpares libelluloides* have relatively weak absorption of the light at wavelength specific for yellow pigments. More pronounced dark parts have higher absorption as well. In comparison with the related species *Libelluloides macaronius* with intensive yellow and black coloured wings (Senčič, 2006), the absorptions were at *P. libelluloides* lower by about 5 and 2 times, respectively. The higher pigmentation of the wings of females, which was determined photometrically, could not be detected with the naked eye. Extraction of yellow pigments revealed 8.3 times higher concentration of them in black spots than in yellow parts of the wings. Owing to the colour stability during the adult stage (D. Devetak, *pers. comm.*) this phenomenon is not a protection effect of black pigments against photodegradation of yellow pigments. The pigments (black melanin, yellow sepiapterin and xanthopterin) were the same as in the wings of *L. macaronius* (Senčič, 2006), which is in accordance with their taxonomic relationship. Although the yellow spots on chromatograms were

in the same positions, the differences were obtained in number and pattern of the spots, which have fluorescence in other colours.

The problem of instability of the pigments in solutions remained unsolved. In dried state (freeze-dried extracts and also in wings), they were stabile on air and daily light for more months, but in solution the colour visibly disappeared in just a few minutes. For this reason, spontaneous oxidation of some pigments may occur during the two-dimensional thin-layer chromatography, as reported for 7,8-dihydrobiopterine (Tomic-Carruthers *et al.*, 1996). For a more detailed qualitative and quantitative analysis, the high pressure liquid chromatography (HPLC) must be used (Tomic-Caruthers *et al.*, 2002), where the sample is not exposed to free oxygen and the time of procedure is short.

ACKNOWLEDGEMENTS

The author is grateful to Dušan Devetak for supplying him with animals and his critical review of the manuscript. Further thanks go to Franc Janžekovič for help in statistical analyses, and to Anita Mustač for her technical support.

DOLOČANJE INTENZITETE OBARVANOSTI KRIL IN IDENTIFIKACIJA PIGMENTOV V KRILIH VOLKCA VRSTE *PALPARES LIBELLULOIDES* (LINNAEUS, 1764) (NEUROPTERA: MYRMELEONTIDAE)

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POVZETEK

Pri volkcu vrste Palpares libelluloides *(Linnaeus, 1764), ki ima bledo rumena krila s črnimi lisami, je avtor s pomočjo absorpcije svetlobe ugotovil intenziteto obarvanosti kril, s kemijsko reakcijo, papirno in tankoplastno kromatografijo pa identificiral pigmente. Intenziteto obarvanosti rumenih delov kril je meril z absorpcijo svetlobe pri valovni dolžini 425 nm, črnih lis pa pri 650 nm. Absorpcije rumenih delov kril so bile pri samicah višje kot pri samcih. V črnih lisah je dokazal obstoj črnega pigmenta melanina. Iz rumenih delov kot tudi iz črnih lis je ekstrahiral rumene pigmente. S papirno in tankoplastno kromatografijo na Silikagelu 60 F_{254} je v obeh vzorcih identificiral sepiapterin in ksantopterin.*

Ključne besede: Neuroptera, Myrmeleontidae, *Palpares libelluloides*, krila, obarvanost, pigmenti

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SHORT-TERM SURFACE CHANGES ON SANDSTONE ROCKS

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ABSTRACT

Short-term measurements, using a traversing micro erosion meter (t-MEM) on sandstone bare surfaces in two different locations within the Peninsula of Muggia, were surveyed. These stations have been monitored since 2004, first using a MEM, then a t-MEM. Median annual lowering rates in the studied stations, resulting from a monthly surveying, is 0.002 mm/yr (MUMV1) and 0.054 mm/yr (MUSB1). Daily surface changes, concerning the relative heights of 22 coordinates, were measured three times a day. The surveying shows that there are significant daily variations on sandstone surfaces. The maximum rise was –0.018 mm, while the maximum lowering was 0.009 mm. Maximum day variation is 0.027 mm. Observations made by various authors about the phenomenon of raising, particularly on shore platforms, is confirmed also for inland sandstones. The observed values suggest that the expansion and contraction of the bedrock could be related to wetting and drying processes. Comparison between meteorological and t-MEM data seems to indicate that during the night, bedrock surface rises due to water absorption, while during the day it lowers owing to the evaporation.

Key words: traversing-MEM, sandstones, surface rise, surface lowering, Muggia

VARIAZIONI MICROTOPOGRAFICHE A BREVE TERMINE DELLE ARENARIE

SINTESI

Vengono discusse misure MEM (micro-erosion meter) e t-MEM (traversing micro-erosion meter) raccolte tre volte al giorno, in due stazioni poste su arenarie, in due diverse località della penisola muggesana. Le stazioni (MUMV1 e MUSB1) sono monitorate mensilmente dal 2004, prima con il MEM ed in seguito con il t-MEM. Il tasso di consumazione media annua nelle stazioni indagate è di 0,002 mm/a (MUMV1) e 0,054 mm/a (MUSB1). Le variazioni superficiali dell'altezza relativa di 22 punti indagine per stazione sono state misurate tre volte al giorno. Lo studio mostra che ci sono significative variazioni giornaliere sulla superficie delle arenarie. Il massimo innalzamento misurato è stato di –0,018 mm, mentre l'abbassamento massimo di 0,009 mm, quindi una variazione massima di 0,027 mm. Le osservazioni fatte da vari autori sul fenomeno dell'innalzamento della superficie, in particolare sulle shore platforms, è confermato anche per le arenarie dell'entroterra. I valori osservati suggeriscono che l'espansione e la contrazione del substrato roccioso potrebbero essere collegati a processi di alterazione dovuti all'alternanza secco/umido tra la notte ed il giorno. La comparazione tra i dati meteorologici e t-MEM sembrano indicare che durante la notte la superficie dell'arenaria si alza a causa dell'assorbimento dell'umidità, mentre durante il giorno la superficie rilascia l'acqua attraverso l'evaporazione.

Parole chiave: traversing-MEM, arenarie, innalzamento della superficie, consumazione della superficie, Muggia

INTRODUCTION

Denudation is understood to be due to chemical and physical weathering and to erosion processes. The estimation of sandstone denudation rates is very important in order to elucidate both the role of sandstones in the geological context and to evaluate the durability of the rocks used as building materials. Many authors investigated weathering processes on sandstones: Takahashi *et al.* (1994) dealt with the reason for the variability and time-dependence in sandstone erosion rates. Paradise (1997) studied the differences between physical and chemical weathering due to lichens covering on sandstones, while Fitzner *et al.* (2003) and Turkington *et al.* (2003) surveyed the effects of weathering on sandstone monuments. Moreover, many researchers investigated the lowering rates of rocks all around the world, using different field or laboratory methods. The first ones did so by repeated measurements of mass or volume loss (Forti *et al.*, 1975; Gams, 1979; Forti & Stefanini, 1981; Stefanini *et al.*, 1985, Plan, 2005) and surface lowering rates via the micro-erosion meter (MEM), traversing micro-erosion meter (t-MEM) or Rock Erosion Meter (REM) (Forti, 1980; Cucchi & Forti, 1986, 1988, 1989; Cucchi *et al.*, 1987, 1996, 1998; Allred, 2004), while the second ones did so through laboratory investigations (Martinez & White, 1999) or through numerical models (Kaufmann & Braun, 2001). Additional surveys have provided the rates of down-cutting in the coastal sector, in particular on shore platforms (Trudgill, 1976; Kirk, 1977; Robinson, 1977; Torunski, 1979; Spencer, 1981; Trudgill *et al.*, 1981; Gill & Lang. 1983; Stephenson & Kirk, 1996; Stephenson, 1997). Among them, Kirk (1977) and Mottershead (1989) measured strange phenomena of surface rises, whereas recently, Stephenson *et al.* (2004), studying short-term changes on shore platforms, found hourly variations in surface height. They used the term "swelling" to describe surface rising. Gomez-Pujol *et al.* (2007) suggest avoiding using the term "swelling", because of its confusion with surfaces that remains elevated due to erosion processes and suggest to use the term "short-term surface change". Their results encouraged us to survey daily variations also in terrestrial setting.

This paper addresses these questions in the light of results from exposure trials conducted at the Muggia Peninsula (Fig. 1) since 2004 (Furlani & Cucchi, 2006). In order to compare the lowering rates of sandstones that outcrop on the Peninsula, we considered the MEM station located at the MUSB site. MUSB sites include 4 measuring laboratory-made stations, one on a micritic limestone from Borgo Grotta Gigante (Italian Karst), one on San Bartolomeo sandstone (studied herewith), one on Kastelir sandstone (studied herewith), and one on a chalk sample from Brighton (UK), collected by Dr. Robinson (University of Sussex). The aim of this paper is to investigate short-term lowering rates via MEM and t-MEM (Fig. 2) on two samples inland sandstones measured during the November 2006 – May 2007 period at the Muggia Peninsula.

MATERIAL AND METHODS

Study area

The Muggia Peninsula is located in the north-eastern part of the Adriatic Sea (Fig. 1). The area is characterized by interbedded sandstones and marlstones belonging to the formation of Eocene Flysch of Trieste. Marlstone layer spacing varies from millimetre to centimetre, while sandstone spacing is higher. Usually, sandstones are well-sorted, 0.1 mm in diameter. The light brown sandstone can be classified as a greywacke, characterized by a relatively high hardness, light brown color and poorly-sorted, angular grains of quartz, feldspar and small rock fragments set in a compact, clay-fine matrix and carbonatic cement. According to Vierthaler (1873) and Malaroda (1947), biotite is less abundant in Muggia, belonging to the "Muggia-Istrian" petrographic area, than in Trieste, belonging to the "Triestine" petrographic area, while density is higher in Muggia. On average, they are composed of quartz (43–53%) and flint (6–11%). The remaining part is composed of feldspar (18–26%) as plagioclase, mica (4–6%), carbonates (16–20% as cement or rock fragments, less abundant in Trieste than in Muggia) and other residual components (iron oxides, glauconite, tourmaline, garnet, zircon and rutil for less than 1–3%). They lack fossils apart from very rare rehandled Globigerinae and locally Medusas. The larger grains can be sand-to-gravel sized, and matrix materials generally constitute more than 15% of the rock by volume.

Geomechanical characteristics of sandstone of the Renice quarry highlight an apparent specific gravity of 2,720 kg m^{-3}, maximum water content of 0.95%, linear thermal expansion coefficient 0.0019 mm/ml/°C, while load strength varies from 945 kg m^{-2} to 908 kg m^{-2} (before and after freezing cycles). The tribometer test shows values of 2.7 mm (http://www.ts.camcom.it/marmi/italiano/marmi/masegno.htm).

The climate in the study area is Mediterranean continental (Righini *et al.*, 2001), characterized by equally distributed rainfall throughout the year, lightly rainier periods in the autumn (mean rainfall 290 mm) and less rainier in the summer (213 mm). Mean annual rainfall measured in the 1961–1990 period in Trieste (0 m a.s.l.) was 1,015 mm yr^{-1}, whereas in the inland Karst area (Padriciano site, 300 m a.s.l.) it was 1,341 mm yr^{-1} (Stravisi, 2003). The minimum mean value was recorded in February, while the daily peak is 105 mm in November. Storms are more frequent at the end of the summer and in the autumn. On average, there are 130 days per year when precipitations occur. In a year there are ap-

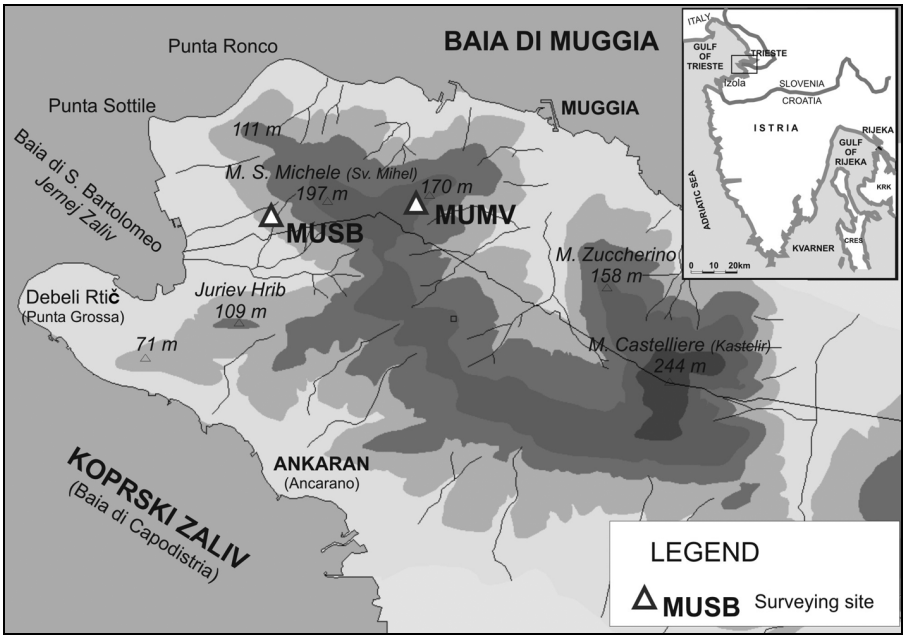

Fig. 1: Map of the Muggia Peninsula (Trieste, Italy) showing the location of the measuring stations (MUSB and MUMV).
Sl. 1: Zemljevid Miljskega polotoka (Trst, Italija) z lokacijami merilnih postaj (MUSB in MUMV).

proximately 31.5% of rainy days, 64.4% of sunny days, 3.0% of snowy days and 1.1% of days with hail (Tommasini, 1979). The hottest month is August (24°C), whereas the coldest one is January with temperatures lower than 6°C.

Sampling

Measurements performed at the selected sites located in the Muggia Peninsula are presented in this work. Each site contains numerous "measuring stations" and each measuring station is composed of three nails fixed on the rock. The MUSB site, located on a private property at Darsella di San Bartolomeo (Lazaret), includes 9 measuring stations. MUSB1 has been the first in operation at this site, as it was positioned on local sandstone in November 2005. MUSB2 surveys the lowering rates of a limestone collected in the Matajur area (Eastern Friuli). MUSB3 has been set to record the lowering rates of limestone collected in Borgo Grotta Gigante (Italian Karst). MUSB4 is placed on Aurisina limestone. The remaining MUSB5, MUSB6, MUSB7, MUSB8, MUSB9 include 5 different rock lithologies: a limestone from Borgo Grotta Gigante, a sandstone from San Bartolomeo, a sandstone from Kastelir Mt., a sandstone from a quarry in Muggia and one sample of chalk from Brighton. Moreover, long-term data collected in MUSB1 to MUMV1 have been compared (Fig. 3). MUMV1 is the oldest station in Muggia. The MUMV site is located in Muggia Vecchia Archaeological Park. The site includes one station positioned in June 2003 on local Eocene sandstone block.

Methods

Direct measurements of limestone lowering rates have been performed using a micro erosion meters (MEM), constructed by Trieste researchers since the 70's,

Fig. 2: The traversing micro erosion meter used in this study.
Sl. 2: Prečni mikro erozijski meter, uporabljen med to študijo.

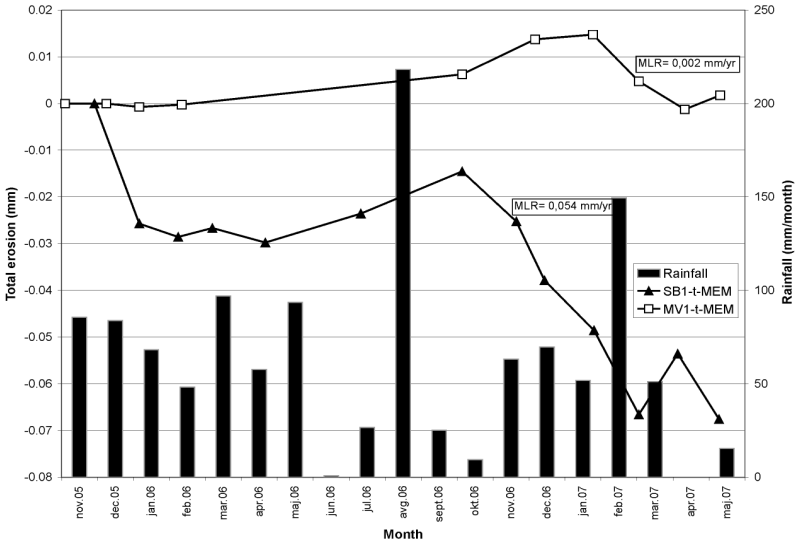

Fig. 3: Long-term lowering rates at MUSB1 and MUMV1.
Sl. 3: Dolgoročne vrednosti posedanja na postajah MUSB1 in MUMV1.

following the High & Hanna (1970) specifications and a traversing micro erosion meter (t-MEM) (Fig. 2). The instrument is equipped with three specially-shaped supports, which are forced to adhere to three bolts or titanium nails, two with semi-spherical and one with flat heads, inserted into the rock. The exact re-location on the fixed bolts is possible thanks to this configuration called Kelvin Clamp Principle. The engineering dial gauge is firmly fixed to the supports, thus allowing highly accurate analyses of rock lowering rates. The lowering rates of the surfaces can be repeated in exactly the same area at pre-set time intervals, using a specially designed engineering dial gauge.

Following the example of Trudgill's team, who constructed a new instrument (Trudgill *et al.*, 1981), the t-MEM, capable of collecting several measurements at each site, the Department of Geological, Environmental and Marine Sciences of the University of Trieste has assembled a t-MEM built by Stefano Furlani. The instrument is equipped with a millesimal-resolution electronic dial gauge, so that readings can be directly downloaded on a laptop computer (Stephenson, 1997). This configuration allows us to obtain a large data set, up to 238 measurements at a bolt site. Due to the large amount of sites, we decided to take 22 readings at each station. A calibration steel base was constructed to periodically check the instrument and to highlight differences in measurements. The electronic dial gauge has a resolution of 0.001 mm, while the error, confirmed by the builder (Mitutoyo), is ±0.003 mm. Probe erosion was estimated using two different methodologies: (1) by repeated readings on a test block, which revealed a probe erosion of 0.003 mm after 100 measures (research performed by the authors of this article) and (2) through observation via microscope of 34 touched rock samples (70 times) and untouched ones (research performed by Prof. Mauro Tretiach and Dr. Paola Crisafulli, Dept. of Geobotany, University of Trieste). In any case, readings below 0.010 mm must be considered with caution (Stephenson *et al.*, 2004).

Readings were taken at MUSB1 station during three periods, between 11 and 12 December 2006, between 26 and 27 February 2007, and between 6 and 7 May 2007. Temperature-related error, as pointed out by several researchers (Spate *et al.*, 1985; Stephenson *et al.*, 2004), was tested, but it turned out to be minimal due to the proximity of sites to the laboratory, in which the instrument is normally stored.

RESULTS AND DISCUSSION

The maximum duration of the measurement record at the stations located at the Muggia Peninsula was exactly 530 days, corresponding to the MUSB1 station, while the MUMV1 measuring site was surveyed for 493 days. The mean annual lowering rate in MUMV1 was 0.002 mm yr^{-1}, while in MUSB1 it was 0.054 mm yr^{-1} (Figs. 3, 4). In the Classical Karst, where measurements have been collected since 1979, lowering rates varied between 0.009 mm yr^{-1} on dolomites, 0.010–0.013 mm yr^{-1}on sparitic limestones and 0.038 mm yr^{-1} on micritic limestones (Cucchi *et al.*, 2006).

Statistics of daily variations for sandstone stations are presented in Table 1. It shows the results between readings collected each day. It contains the date of surveying, the number of surveyed points, the number of readings, the mean lowering/raising value, the median, the maximum and minimum surveyed value, the standard deviation and variance for daily variations. Negative values indicate a rising while positive values indicate lowering.

Tab. 1: Muggia descriptive statistics of changes (mm) between measurements.
Tab. 1: Statistika sprememb (mm) med merjenji na Muljskem polotoku.

Date	Surveyed points	Readings	Mean (mm)	Median (mm)	Max (mm)	Min (mm)	Range (mm)	SD	Variance
11-12/12/07	22	66	0.008	0.007	0.027	0.003	0.024	0.005	0.000
26-27/02/07	22	88	0.010	0.010	0.019	0.005	0.014	0.003	0.000
06-07/05/07	22	132	0.008	0.007	0.015	0.004	0.011	0.003	0.000

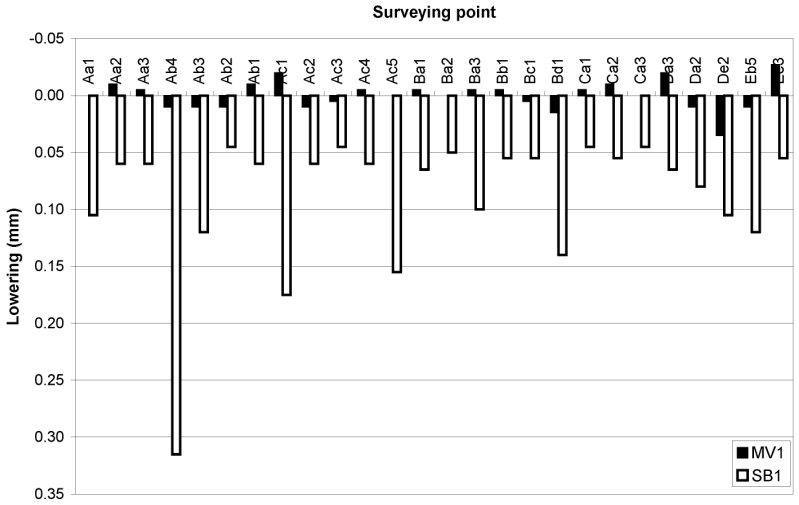

Fig. 4: Total annual surface change (mm) at MUSB1 and MV1 stations.
Fig. 4: Skupna letna sprememba (mm) na površju peščenjakov na postajah MUSB1 in MV1.

The global mean daily change is 0.009 mm (Fig. 5). On average, subsequent readings were not higher than 0.003 mm. Daily variations for each set of surveying points on each considered day do not show a normal trend and a large standard deviation affects measurements, so the most appropriate measure of central tendency is the median or the truncate average.

Daily measurements collected on sandstones in Muggia are shown in figure 6, together with humidity and temperature variations:

- three times (22:00, 9:00 and 13:00 h) on 11 and 12 December 2006. Measurements highlighted median diurnal variations of 0.007 mm, maximum surface change up to 0.027 mm, minimum 0.003 mm and a standard deviation of 0.005 mm.

- four times (22:00, 9:00, 13:00, 18:00 and 22:00) on 26 and 27 February 2007. Measurements highlighted median diurnal variations of 0.010 mm, maximum surface change up to 0,019 mm, minimum 0.005 mm and a standard deviation of 0.003 mm.

- four times (18:00, 22:00, 9:00, 13:00, 18:00, 22:00) on 6 and 7 May 2007. Measurements highlighted median diurnal variations of 0.008 mm, maximum surface change up to 0.015 mm, minimum 0.004 mm and a standard deviation of 0.003 mm.

The influence of a thin film of water on the rocky surface compared to a completely dry surface was tested in laboratory on the steel calibration block. A total amount of 144 measurements on dry surface and 88 measurements on wet surface was performed. Differences among them are lower than the estimated error of the instrument (0.004 mm).

From the analysis of t-MEM data, it was found out that there were significant variations in micro-topography during the day. It seems that these variations do not occur in a homogeneous pattern on the sandstones. Following previous cited works (Stephenson *et al.*, 2004; Gomez-Pujol *et al.*, 2007) we classified height variations of points as rising, falling and stable. Most of the points showed to fall during the day, probably due to the decrease in humidity and because of the solar heating, while there was a rising tendency during the night (the maximum rises were surveyed in the morning) as the humidity increased. Measurements collected on the steel calibration block showed that water did not influence directly the surface variations that considering the thickness of water would not change the surveyed values. This means that short-term variability in t-MEM values was no doubt due to a process occurring near the rock surface. Probably wetting and drying, as demonstrated by Mottershead (1989) and Stephenson *et al.* (2004), could be the most important factors on inland sandstones, too. On the subject, Blend & Rolls (1998) stated that wetting and drying is closely related to hydration shattering and could be related to

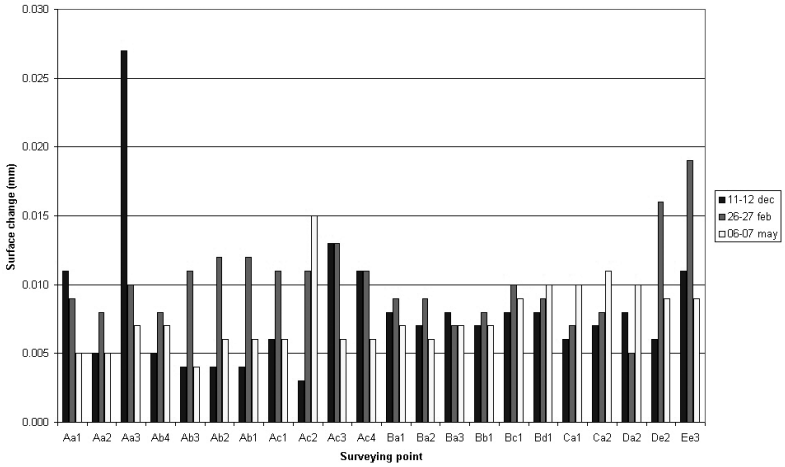

Fig. 5: Total surface variations (mm) recorded at the measuring stations during the three samplings performed in December 2006, February and May 2007.
Sl. 5: Skupne razlike (mm) na površju peščenjakov, izmerjene na postajah med tremi vzorčenji decembra 2006 ter februarja in maja 2007.

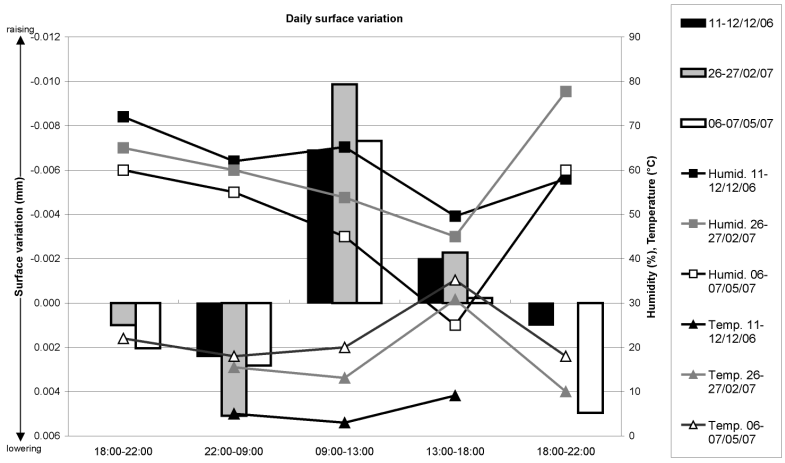

Fig. 6: Daily surface variations (mm) recorded at the measuring stations during the three samplings performed in December 2006, February and May 2007.
Sl. 6: Skupne dnevne razlike (mm) na površju peščenjakov, izmerjene na postajah med tremi vzorčenji decembra 2006 ter februarja in maja 2007.

unsatisfied electrostatic bonds in the surface minerals. The polar water molecules will be attracted by minerals in the small cracks of the surface, making a layer of adsorbed water. The addition of further water, as affirmed by the above mentioned authors, may cause a swelling-pressure which may in turn create strain. When water disappears, in this case by diurnal evaporation, the sides of the crack may be pulled together as attractive force. Cycles of wetting and drying could trigger diurnal expansion and contraction of the sandstone surface. Moreover, the surveyed sandstones are easily dependent on wetting and drying processes because of the presence of clay minerals, which help water absorption, some cleavage plains, which favour water penetration, and of high surface porosity.

CONCLUSIONS

Sandstone micro-erosion meter located in the Muggia Peninsula highlighted significant day-to-day variations. Inland sandstone surfaces seem to be a dynamic entity, showing both annual (from 0.002 to 0.107 mm yr^{-1}) and short-term (from -0.018 to 0.009 mm) lowering/raising rates. Our findings suggest that attention should be paid to the evaluation of t-MEM data, because they could cause an under- or over-estimation of the annual rates. Such variation had been previously reported in coastal environments and has now been surveyed on inland sandstone, too. The analysis of data on sandstones show that wetting and drying are the main processes concerning this phenomenon since raising/falling

values are closely connected to daily variations in humidity, as already reported by Stephenson *et al.* (2004) on shore platforms. Further studies to elucidate the mechanisms of lowering, to investigate the internal properties of the sandstones and to compare sandstones changes to other rocks are needed.

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KRATKOROČNE SPREMEMBE NA POVRŠJU PEŠČENJAKOV

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POVZETEK

Avtorja pričujočega članka sta z uporabo prečnega mikro erozijskega metra (t-MEM) merila kratkoročne spremembe na golih površinah peščenjaka na dveh lokacijah na Miljskem polotoku (Muggia). Na teh postajah meritve potekajo že od leta 2004; najprej so bile opravljene z uporabo MEM, nato z uporabo t-MEM. Glede na mesečne meritve sta srednji letni vrednosti posedanja na preučevanih postajah 0,002 mm/leto (MUMV1) in 0,054 mm/leto (MUSB1). Dnevne spremembe na površju so bile merjene trikrat na dan z relativnimi višinami 22 koordinat. Meritve so pokazale, da na površju peščenjakov nastajajo pomembne dnevne razlike. Največji zabeleženi dvig je bil –0,018 mm, maksimalni ugrez 0,009 mm. Maksimalna dnevna razlika je znašala 0,027 mm. Opažanja, ki so jih o dviganju zabeležili različni avtorji predvsem na obrežnih terasah, so bila potrjena tudi za peščenjake v notranjosti. Zabeležene vrednosti nakazujejo, da je širjenje in krčenje površja substrata lahko povezano s procesoma močenja in sušenja. Primerjava med meteorološkimi podatki in podatki t-MEM kaže, da se površje substrata ponoči zaradi vsrkavanje vode dviga, medtem ko se ponoči zaradi izhlapevanja niža.

Ključne besede: prečni MEM, peščenjak, dviganje in nižanje površja substrata, Milje

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PALAEOMAGNETIC RESEARCH INTO UNROOFED CAVES OPENED UP DURING THE HIGHWAY CONSTRUCTION AT KOZINA, SW SLOVENIA

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ABSTRACT

*The construction of highway from Divača to Klanec (SW Slovenia, Classical Karst) uncovered a number of fossil caves and unroofed caves. Two of them were situated near Kozina. One (sites A and B) represented unroofed fossil channel rests of collapsed roof. It formed mild depression in the field. The sedimentary profile in cave was about 5 m high. The second (*site *C) was oblong shallow depression with nearly 8 m thick sequence. The profile at* site *A contains inverse and normal polarity magnetozones. The age of the profile at Kozina is older than Bruhnes/Matuyama boundary (0.78 Ma). According to the arrangement of individual magnetozone, it could be stated that sediments are older than the top of Olduvai chron (1.77 Ma), profile at* site *C is interpreted as younger than 0.78 Ma. We suppose that the fossil caves at Kozina are the result of post-Eocene speleogenetic epoch and its fossilization was connected with tectonic uplift of the area, probably after Messinian. If this hypothesis is close to the reality, the fossilization process could start at about 5.3 Ma as already expected.*

Key words: paleomagnetic analyses, cave sediments, roofless caves, Kozina, Slovenia

RICERCA PALEOMAGNETICA IN GROTTE SENZA TETTO, APERTE DURANTE LA COSTRUZIONE DELL'AUTOSTRADA NEI PRESSI DI COSINA, SLOVENIA SUD-OCCIDENTALE

SINTESI

La costruzione dell'autostrada da Divaccia a S. Pietro di Madrasso (Slovenia sud-occidentale, Carso classico) ha portato alla scoperta di numerose grotte fossili e grotte senza tetto. Due di queste sono situate nei pressi di Cosina. Nella prima (siti A e B) ci sono i resti del tetto crollato di un canale fossile, che formava una leggera depressione nel terreno. Il profilo sedimentario della grotta era alto circa 5 m. La seconda (sito C) era una depressione oblunga e poco profonda, con una sequenza spessa circa 8 m. Il profilo nel sito A contiene magnetozone con polarità inversa e normale. L'età del profilo di Cosina è superiore a quella del limite Bruhnes/Matuyama (0,78 milioni di anni). Conformemente alla disposizione delle singole magnetozone, gli autori suppongono che i sedimenti siano antecedenti la fine dell'evento Olduvai (1,77 milioni di anni), mentre il profilo del sito C sarebbe più giovane di 0,78 milioni di anni. Gli autori ipotizzano che le grotte fossili di Cosina siano il risultato di un'epoca speleogenetica post-Eocenica e che la loro fossilizzazione sia correlata al sollevamento tettonico dell'area, avvenuto probabilmente dopo il Messiniano. Se tale ipotesi corrisponde a realtà, il processo di fossilizzazione potrebbe essere iniziato circa 5,3 milioni di anni fa.

Parole chiave: analisi paleomagnetica, sedimenti di grotta, grotte senza tetto, Cosina, Slovenia

INTRODUCTION

The Classical Karst is the low NW-SE trending longitudinal plateau along the Gulf of Trieste in the NE Adriatic Sea extending from the Vipava Valley in the NE to Friuli-Venezia Giulia lowlands and the Soča River in the NW. Its length is about 40 km, whereas its width reaches 13 km. It covers a total of about 440 km^2. Its central part is situated at 200 to 500 m a.s.l.

The Kras plateau belongs to the Adriatic-Dinaric Carbonate Platform of the External Dinarides. It is composed of relatively shallow marine Cretaceous and Palaeogene limestones rich in fauna and flora. Eocene flysch sediments encircle carbonate plateau. Due to the strong pressures in the NE→SW direction, a complicated geological structure was formed with an alternation of flysch and limestone zones (slices) elongated in the NW-SE direction. Thrust planes are dipping towards the northeast *(cf.* Placer, 1981).

The area around Kozina is geologically dominated by an anticline that runs south from Kozina to the northern slopes of Slavnik Mountains in the Dinaric direction. The caves developed in the Upper Cretaceous limestones close to the tectonical contact with alveolinid and nummulitic limestones of Eocene age (Thanetian). Tectonic contact with Eocene siliciclastics (flysch) was located near the construction site.

The karstification of the region is characterized by the presence of old caves partly crossed by younger shafts. Shafts are connected with the drop of underground water level, which is presently situated about 200 m below the surface. Shafts are both empty and filled with young (Pleistocene) sediments *(e.g.*, Brodar, 1958; Rakovec, 1958).

Large valley systems on the surface of the Karst were believed to represent primary river valleys as they contain remnants of fluvial sediments. Nevertheless, after the start of identification of unroofed caves *(sensu* Mihevc, 1996), we know that fluvial sediments represent rather fill of fossil caves than remnants of surface fluvial systems *(cf.* Mihevc, 1998, 1999a, 1999b, 1999c, 2001). The palaeofill of caves appeared at surface due to erosion and chemical denudation of limestone surface, which is estimated at 20–50 m in 1 million years (Gams, 1981; Cucchi *et al.*, 1994).

The unroofed caves have been preserved as fluvial deposits and spelothems on the present surface, sometimes with traceable course of original passages. Such caves were originally described during the construction of highway network over the Classical Karst *(e.g.*, Knez & Šebela, 1994; Šebela & Mihevc, 1995; Slabe, 1996, 1997, 1998; Mihevc, 1996; Mihevc & Zupan Hajna, 1996; Kogovšek *et al.*, 1997; Mihevc *et al.*, 1998; Šebela 1999; Šebela *et al.*, 1999; Knez & Slabe, 1999a, 1999b, 2002, 2004a, 2004b, 2005, 2006). Altogether, 350 caves have been discovered along some 70 km long and 25 m wide construction strip of the highway. Among them, 50 were unroofed. Some of them represented parts of the same cave palaeosystem(s). Later on it was established that such caves are common over the whole Classical Karst *(e.g.*, Mihevc, 1998; Šusteršič, 1998; Geršl *et al.*, 1999; Stepišnik & Šusteršič, 1999).

Mihevc *et al.* (1998), and Knez & Slabe (1999a, 1999b, 2002) tried to classify the typical forms of unroofed caves. They are transformed by surface processes and represent an important element of the epikarst zone (Knez & Slabe, 1999b). The shape and form of unroofed caves resulted from the morphology of present surface, original configuration of fossil caves, intensity of younger karstification (speleogenesis) and a degree of younger exhumation of the cave fill. In the field, they are expressed as shallow oblong depressions, doline-like forms and collapsed dolines. Unroofed caves are a typical example of denudated karst *(sensu* Bosák *et al.*, 1989) – partially incorporated into the present karst landscape and hydrological system.

The dating of sediments in some unroofed caves by palaeomagnetic method (Bosák *et al.*, 1998, 1999, 2000a, 2000b) indicated the substantial age of the cave fill, clearly older than 1.77 Ma, some even up to 3.2 Ma. Ages of interpreted magnetozones at two sites were calibrated by finds of small mammals at the time interval of about 2.0 Ma (Račiška pečina Cave, fossil cave in the Črnotiče Quarry) (Bosák *et al.*, 2004a, 2004b; Zupan Hajna *et al.*, 2007).

Paleomagnetic research into cave sediments in Slovenia initiated in 1999 by Bosák *et al.* (2000a) and Šebela & Sasowsky (2000) during the construction operations along the route of Divača-Klanec section of the highway. They studied two sedimentary profiles at one unroofed cave and one profile in somewhat distant palaeocave. Sampling sites were located in a cut carved during construction about 400 to 900 m NE from Kozina close to the former Ljubljana – Koper main road. The area is situated at about 520–540 m a.s.l. within typical karst landscape with dolines and collapse dolines.

MATERIAL AND METHODS

Site characteristics

Knez & Slabe (1999b) described in detail the character of unroofed caves in the vicinity of Kozina. The network of various karst forms (Fig. 1), resulting from unroofing of large and diversified cave system(s), spreads along the construction site. The largest cave system – 400 m long – was situated on the right side of construction near Kozina. The system appeared on the surface as more or less distinct oblong depressions forming the connection of doline-like depressions. Unroofed caves were morphologically more expressed near dolines, where erosion of cave fill down to dolines was more in-

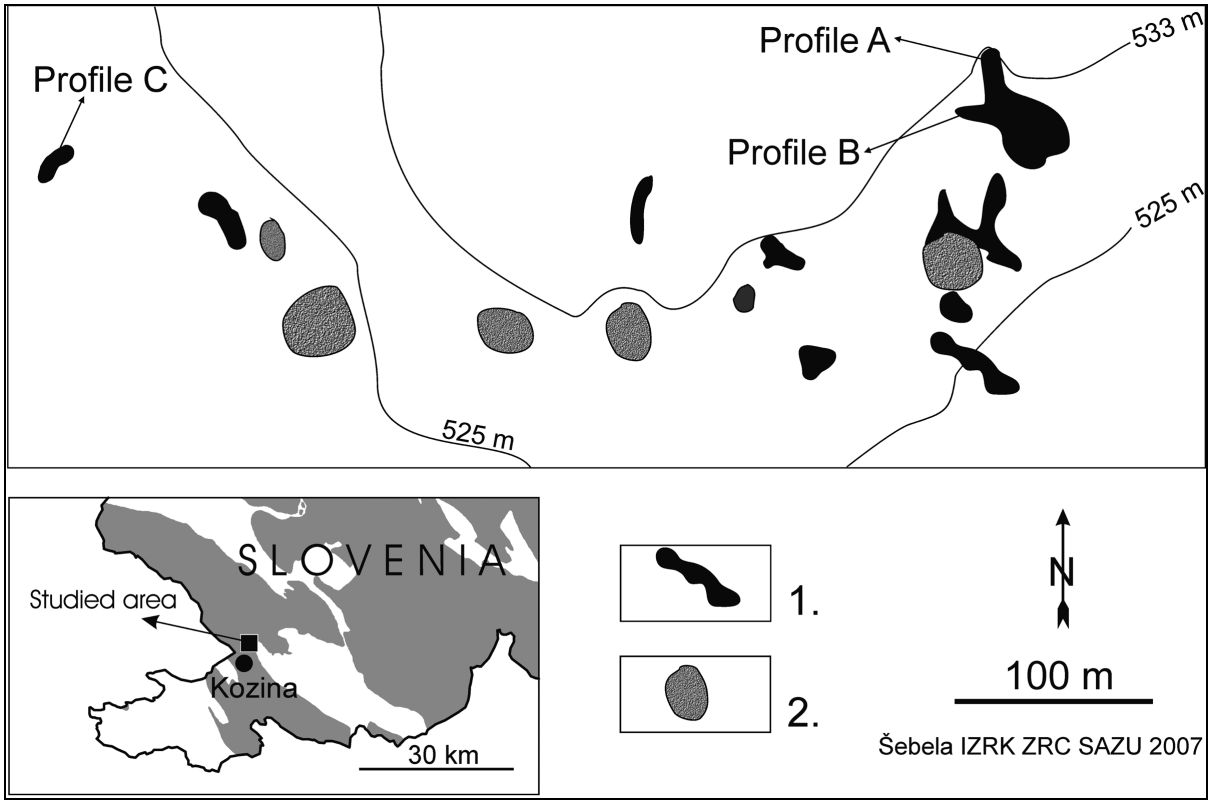

Fig. 1: Site location. Legend: 1 – unroofed cave; 2 – doline.
Sl. 1: Položaj profilov. Legenda: 1 – brezstropa jama; 2 – vrtača.

tensive. Depressions were mostly small and shallow. Their bottoms were filled by brown and red soils several metres thick. There were traces of water flow at the contact soil/limestone. At their bottoms, there were entrances to narrow and inaccessible shafts.

Cave passages were both free and choked, with very thin roofs, which have been partly removed. Caves were filled predominantly by fine-grained fluvial sediments, sometimes with gravel beds derived from flysch sediments. In the SW, piles of flowstones and stalagmites formed intercalations with fluvial cave fill. Some sedimentary sections were covered by angular blocks, boulders and debris derived from destructed roof limestones (Fig. 2). The debris is expected to be the result of weathering/disintegration in cold Pleistocene climate (Knez & Slabe, 1999b).

Profile description

SITE A. The log of sampled profile is presented in figure 3. The whole profile consisted of more than 5 m thick sediments. Its bottom was uncovered. The fill was composed of two principal sequences. The lower one was composed of ochreous sandy to clayey sediments, which are about 3 m thick. Sediments of lower sequence were sampled for palaeomagnetism. The lower sequence was overlain with sharp erosional surface by collapse breccia with limestone blocks to boulders (cm to m in size) and matrix of brown loams with carbonate efforescences on cracks (pseudomycelia). In the upper part of collapse breccia, the matrix was rather ochreous with smaller rock fragments. The upper sequence was not sampled for palaeomagnetic analysis owing to the collapse character with possibility of postdepositional movement, slumping and sediment rotation.

Near the contact of sediments and limestone, narrow inclined cavity developed in sediments of the lower sequence. The cavity walls were covered by speleothems, which cemented surrounding sediment. The cavity represents younger waterway draining the fossil cave and shallow depression of the present surface.

Lower sequence was about 3 m thick. Palaeomagnetic samples are signed in cm from the base of the profile (sample No. 2–295). Following lithological units, the following was distinguished: **1.** Sand, yellow, black-violet schlieren, very fine-grained, silty, indistinct lamination with higher clayey admixture, angular rock fragments. **2.** Clay, silty, variegated (ochreous, light brown with dark grey and violet schlieren and lamination), slightly finely sandy, more at the base, laminated (dynamic lamination), erosional base with secondary ferruginisation (2–28). **3.** Clay, silty, ochreous to light brown,

Fig. 2: The complete profile A in road cut near Kozina.
Sl. 2: Celoten profil A v cestnem useku blizu Kozine.

yellow and whitish yellow laminated, with laminae of fine-grained sand and fine sandy silt, thin ferruginized laminae, erosional base (29–93). **4.** Clay, light brown, violet brown at the top, with thin white sand bend, erosional base (98–109). **5.** Clay, silty, ochreous to light brown, yellow and whitish yellow laminated, with laminae of fine-grained sand and fine sandy silt, clasts of brown clays in the upper part, in places calcitized, erosional base, disconformably on layer No. 4 (some 10° lower inclination) (116–212). **6.** Clay, silty, light brown, erosional base (219–231). **7.** Clay, silty, light brown, slightly finely sandy in indistinct laminae, with coarse flakes of micas, with irregular clasts, erosional base. **8.** Breccia with light ochreous clayey matrix, erosional base. **9.** Clay, silty, brown, with Mn schlieren, erosional base (290). **10.** Sand, yellow, fine-grained, with cross-bedding, erosional base (295).

Five samples were taken from the profile for palynological analyses, *i.e.* at 30, 30–45, 70–80, 130–150 and 180–200 cm from the profile base. Sample from 70–80 cm yielded two highly corroded pollen grains belonging to herb vegetation *(Dipsacaceae and Apiceae family)* typical of dry, steppe-like region with any stratigraphic value. Sample from 130–150 cm yielded one spore (fern).

SITE B. The site was situated several metres to the south from the site A (Figs. 1, 4). The profile was 164 cm thick. The lower part of this profile was at an elevation of 527 m a.s.l. On the top of the cave sediments, which were mostly laminated clays, a cave roof to the thickness of 0.5 m was still preserved. The colour of the sampled sediments was determined by comparison to Munsell Soil Chart: SLO033-SLO034 (7.5YR 6/8-redish yellow) and SLO035-SLO036 (7.5YR 5/8-strong brown). We took 4 samples (SLO033-SLO036).

SITE C. The site was situated about 500 m to the west of the site B (Figs. 1, 5). The thickness of cave sediments was 7.84 m. The column was probably thicker, but it was not possible to dig the material out and reach the original bottom of the cave. The upper part of the profile is a 7.4 m thick massive sandy layer with weathered flysch gravels of 5 cm average diameter.

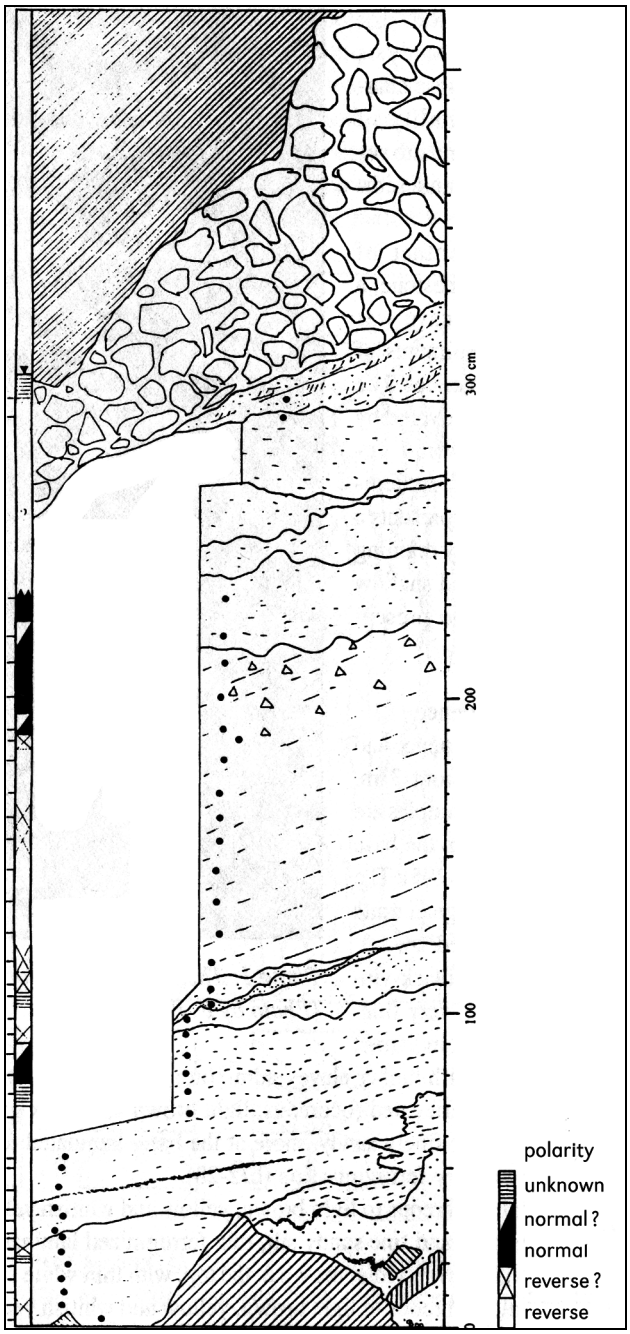

Fig. 3: Lithological log of the profile Kozina Site A with magnetic polarisation (Bosák** et al., **2000b), with black dots indicating sampling points.
Sl. 3: Litološka skica profila Kozina, vzorčno mesto A z magnetno polarizacijo (Bosák** et al., **2000b). Črne pike so točke vzorčenja.

Below this sandy layer lies a 20-cm thick layer of loam, and a sandier bedded clay layer below it. We took 6 samples (SLO037-SLO042). The colour of the sampled sediments was determined by comparison to Munsell Soil Charts: SLO037-SLO038 (7.5YR 5/8- strong brown), SLO039-SLO040 (7.5YR 6/8- reddish yellow) and SLO041-SLO042 (10YR 5/6- yellowish brown). Samples were taken at an altitude of about 522 m a.s.l. On the top of cave sediments, about 1–1.5 m thick layer of rubble has been preserved in some places. However, the original cave roof was no longer existent.

Palaeomagnetic analyses

Plastic sampling cubes with volume of about 8 cm^3 were inserted into a clean sediment face. Strike, dip direction, dip, and tilt of the cubes were recorded

Altogether, 38 oriented laboratory specimens of cave sediments were investigated as to their palaeomagnetic properties from the site A, 4 specimens from site B, and 6 specimens from site C.

Laboratory specimens were measured on the spinner magnetometers (JR-4 and JR-5; Jelínek, 1966). Laboratory specimens of solid sample in a natural state were subjected to progressive thermal demagnetization (TD) on the MAVACS (Magnetic Vacuum Control System) generating high-magnetic vacuum (Příhoda *et al*. 1989). All specimens were demagnetized by alternating field (AF; Schonstedt GSD-1), up to the field of 1,000 Oe in 14 steps. The susceptibility of specimens demagnetized by the TD procedure (k_t) and values of volume magnetic susceptibility of specimens in the natural state (k_n) values were measured on a kappa-bridge KLY-2 (Jelínek, 1973).

The directions of remanent magnetization (J_n) and those of the remanent magnetization (M) of demagnetized specimens by the TD or AF procedure in the course of progressive demagnetization procedures were done. The separation of the respective remanent magnetization components was carried out by multi-component Kirschvink analysis (Kirschvink, 1980). The statistics of Fisher (1953) were employed for calculation of mean directions of the pertinent remanence components derived by the multi-component analysis.

The samples were refrigerated and protected from strong magnetic fields after being collected. Magnetic properties were determined at the University of Pittsburgh Palaeomagnetic Laboratory. Magnetic strength and direction were measured on a superconducting rock magnetometer housed in a shielded room. Natural remnant magnetization (NRM) was measured first, followed by step-wise alternating field demagnetization and additional remnant magnetization measurements.

RESULTS

Palaeomagnetic results

SITE A. All collected samples (totally 38) were subjected to the AF demagnetization; one sample was demagnetized thermally. The values of the module of J_n of rocks in natural state show big scatter. Mean values of module of remanent magnetization J_n and of magnetic susceptibility k_n in their natural state from 38 samples are J_n = 7.005 ± 8.391 [nT], k_n = 267 ± 216 x 10^{-6}[SI]. Rocks show low or medium degree of magnetization.

The directions of remanent magnetization inferred by the above given procedures were tested by multi-component analysis. Generally, the samples showed three remanence components. *A-components* are mostly of viscose or chemoremanent (weathering) origin. They can be removed by alternating field with the intensity of 10 up to 30 Oe. Detected remanent magnetization in a natural state varies between 95 and 36,470 pT, with the values of volume magnetic susceptibility ranging from 55 to 998 x 10^{-6} SI. Some samples showed expressive viscose component (up to 90%); the primary component of magnetization and resulted polarity therefore cannot be stated.

Normal and reverse *C-component* directions of the samples form two defined sets of samples with the fisherian distribution. Mean directions of remanent magnetization of the Kozina profile are documented in Table 1.

The top and lower part of the profile shows reverse magnetozone. There are two normal zones in the middle part of the profile.

Tab. 1: Mean palaeomagnetic directions: Kozina, site A.
Tab. 1: Srednje paleomagnetne smeri: Kozina, vzorčno mesto A.

Locality	Polarity	Mean directions of the remanent magnetisation D[°]	I[°]	α_{95}	k	n
Kozina	N	338.2	62.3	20.7	8.1	8
	R	206.0	-67.6	20.1	3.1	25

SITES B AND C. The samples had a strong magnetic signal, with NRM values near 10^{-5} kA^{-1}. However, due to low-coercivity most of this signal was removed by application of a 20 mT alternating field.

Principle components analysis (Kirschvink, 1980) was used to fit a vector through the demagnetization data points for each sample. The resulting field directions were then plotted. The sample pairs in general

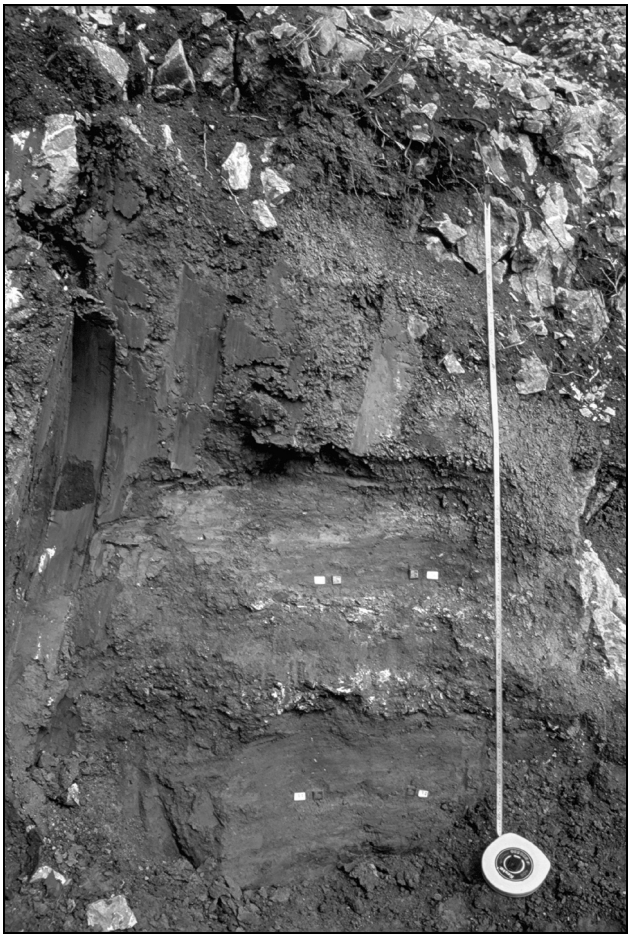

Fig. 4: Profile site B.
Sl. 4: Vzorčno mesto B.

Fig. 5: Profile site C.
Sl. 5: Vzorčno mesto C.

showed good correlation (indicated by light dashed lines in figure 6). Samples from the first location clustered slightly west of the present day field, with a somewhat greater inclination. This steepening of inclination is unusual in our experience. Samples SLO037 and SLO038 did not show a good match. The remainder of samples from the second location clustered tightly near the present day field.

Magnetic susceptibility was measured in 2 orientations using a Sapphire Instruments device. Values ranged from $1x10^{-5}$ to $7.5x10^{-5}$ (cgs units) with an average of $5x10^{-5}$. These are relatively high values for cave sediments. There was no anisotropy of susceptibility. Cave sediments from both sites showed only normal magnetic polarity.

Magnetostratigraphic results

SITE A. Palaeomagnetic and magnetostratigraphic investigations yielded data on basic magnetic properties and identification of palaeomagnetic directions: (i) magnetostratigraphic results defined normal and reverse polarity magnetozones, and (ii) magnetostratigraphic results of samples from Kozina and Divača profiles (Bosák *et al.*, 1998) show close similarities (Fig. 7): (a) two normal subzones in reverse magnetozone were interpreted within both profiles, and (b) good correlation of module values of remanent magnetization (J_n).

SITE B. It was located stratigraphically above site A, where the profile terminates by normal polarized section (Bosák *et al.*, 2000b). Results from both sites are compatible, as sediments of site B are higher and show normal polarity, indicating they are of the same age as upper part of the site A or younger.

DISCUSSION

SITE A. The lithology of profile clearly shows two-phase depositional history. The lower sequence, after its deposition, was partly eroded. The erosional channel was more deeply developed on the left side of the passage. The free space between sediment and the cave

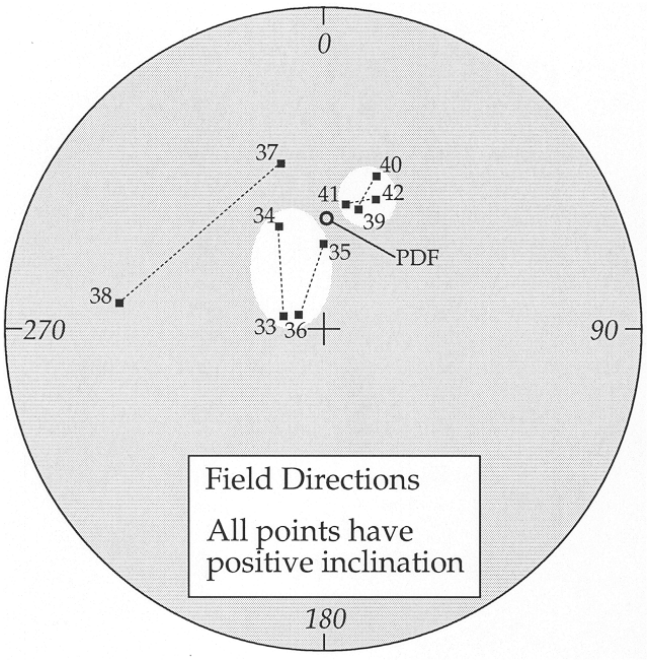

Fig. 6: Lambert equal area stereoplot of magnetic field directions for profiles B and C. Sample numbers (series SLO) are adjacent to sample squares. Present-day field is shown as bold circle. Light areas indicate possible clustering of field directions.
Sl. 6: Lambertov stereografski prikaz enakih področij smeri magnetnega polja za vzorčni mesti B in C. Številke vzorcev (oznaka SLO) ustrezajo kvadratkom. Današnje magnetno polje je označeno s sivim krogom. Svetlejša polja nakazujejo mogoče združbe smeri polj.

ceiling in the cave was later filled during collapse processes by block to boulder debris mixed with brown sediments. Ochreous intercalations in the upper part of the upper sequence can indicate the presence of eroded sediments comparable with the lower sequence. Thinning of cave roofs by erosion and karst denudation induced their collapses.

Lithological composition of the lower sequence is comparable with the Divača profile in a fossil cave near the village of Divača (Bosák *et al.*, 1998); with its sequences Nos. I and II. Layer No. 10 of the Kozina profile it could particularly be correlated with the base of sequence No. III of the Divača profile. It seems that sediments were derived from similar source rocks, most probably from weathered Eocene flysch.

Important erosional boundaries of the main lithological units within the lower sequence are located between samples Nos. 28/29, 93/98, 109/116, 212/219, 290/295. In contrast to other studied profiles (Bosák *et al.*, 2000a), erosional boundaries are not situated at boundaries of normal and reverse polarized zones, but within them. This fact can also indicate that breaks in deposition did not take a substantial time-span.

The magnetostratigraphic picture obtained in the Kozina profile is fully comparable with magnetozones detected in the Divača profile (Bosák *et al.*, 1998, 2000a), both in occurrence of the normal and reverse polarized magnetozones and in the character of the module of remanent magnetization (J_n). The dominant part of both profiles is represented by reversed magnetozones. There are two relatively narrow normal polarized zones. Unfortunately, there is a gap in sampling between the Kozina samples No. 213 and 290, owing to rock petrography unfavourable for sampling. Some difference in the arrangement of normal polarized magnetozones in both profiles can also result from different rates of deposition during fossilization of both channels.

The age of the profile at Kozina is older than Bruhnes/Matuyama boundary (0.78 Ma). According to the arrangement of individual magnetozones, it could be stated that sediments are older than the top of Olduvai chron (1.77 Ma), as the magnetostratigraphic profile at Kozina terminates by reverse polarized magnetozone and contains two normal polarized zones. Closely comparable character of module values of remanent magnetization (J_n) highly supports the age correlation of both profiles from fossil caves at Divača and Kozina.

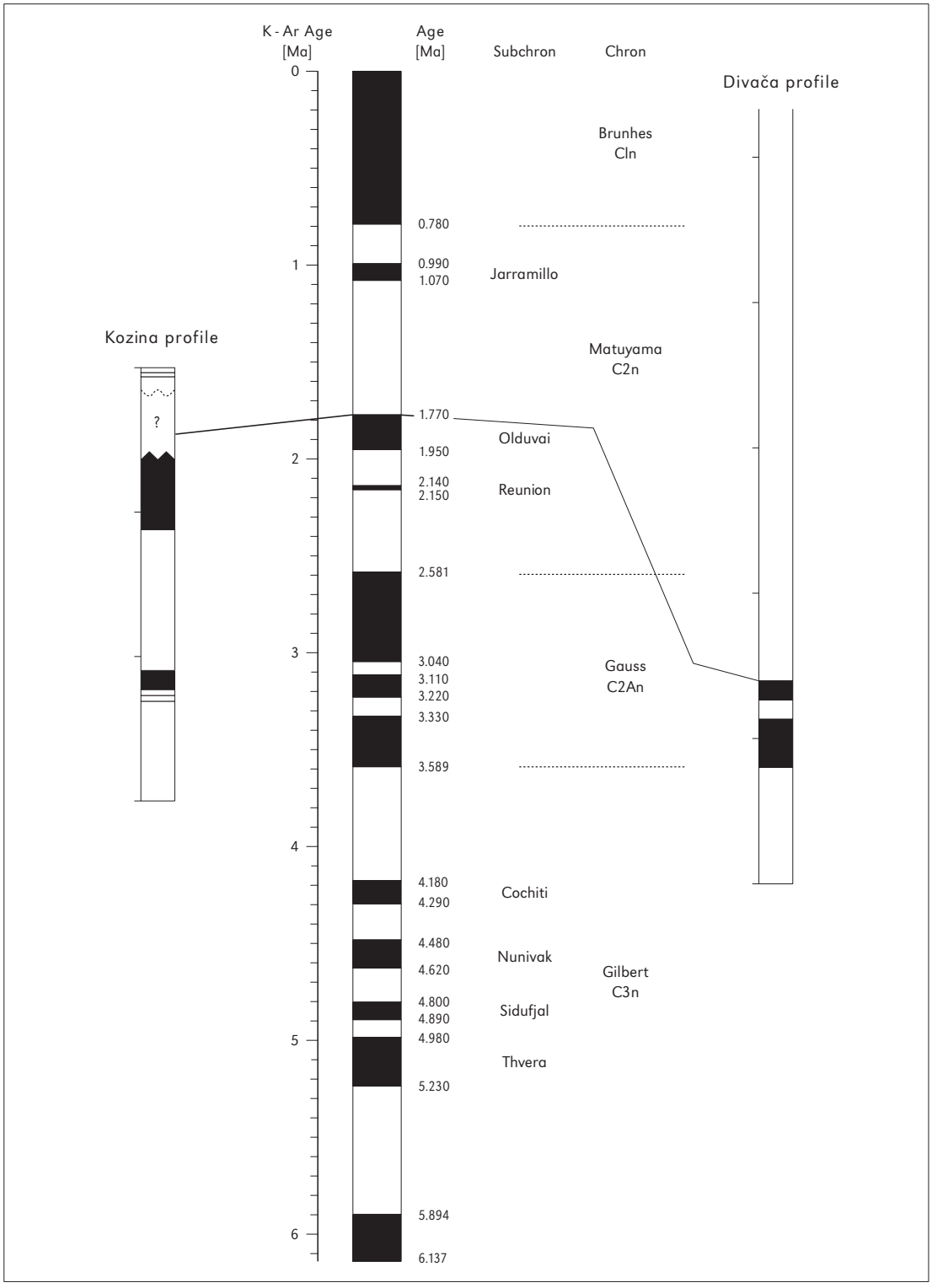

Fig. 7: Correlation of magnetostratigraphic results from Kozina site A (left; Bosák** et al., **2000a, 2000b) and Divača profile (right; Bosák** et al., **1998) with the standard palaeomagnetic scales (centre; after Cande & Kent, 1995).
Sl. 7: Korelacija pridobljenih magnetostratigrafskih rezultatov iz Kozine, vzorčno mesto A (levo; Bosák** et al., **2000a, 2000b) in Divače (desno; Bosák** et al., **1998) s standardnimi paleomagnetnimi lestvicami (sredina; po Cande & Kent, 1995).

SITES B AND C. Palaeomagnetic analysis of cave sediments from sites B and C showed that all of the 10 samples have normal polarity. Based on sample mineralogy, the source for all analyzed cave sediments was the Eocene flysch.

Cave sediments from site B (SLO033-SLO036) are almost certainly younger than 0.78 Ma. This is consistent with the studies by Bosák *et al.* (2000b). Regarding their results, which show that sediments are older than 0.78 Ma, our profile is younger than 0.78 Ma, because it was stratigraphically higher.

Site C has a thicker profile, and we collected sediments from its lower part. Regarding our results that show normal polarity, it is difficult to conclude that sediments are really younger than 0.78 Ma. If we consider the fact that sediments from roofless caves can be older than 0.78 Ma and that those samples were taken from the lower part of 7.5 m thick profile, we can suggest a possibility that they may have been deposited during an older normal polarity period. They could even be from the Gauss Normal chron (2.48–3.4 Ma), or according to Bosák *et al.* (1998) could correlate with some normal magnetozones (about 3.8–5.0 Ma) within the reverse Gilbert chron.

CONCLUSIONS

The construction of highway from Divača to Klanec (SW Slovenia, Classical Karst) uncovered a number of fossil caves and unroofed caves. Two of them were situated near Kozina. One (sites A and B) represented unroofed fossil channel. It formed mild depression in the field. The sedimentary profile in the cave was about 5 m high. It was composed mostly of sandy sediments of light brown colour with clayey and silty intercalations. Sediments contained dynamic structures and textures (lamination, cross-lamination, etc.). Erosional surfaces divided the profile into individual sequences. The second (site C) was oblong shallow depression with nearly 8 m thick sequence of brown to yellow-coloured sands with some silt to clay beds in the lower part. The profile was covered by limestone gravel.

The profile at site A contains inverse and normal polarity magnetozones. The age of the profile at Kozina is older than Bruhnes/Matuyama boundary (0.78 Ma). According to arrangement of individual magnetozone, it could be stated that sediments are older than the top of Olduvai chron (1.77 Ma), as the magnetostratigraphic profile at Kozina terminates by reverse polarized magnetozone and contains two normal polarized zones. Profiles at sites B and C showed only normal magnetic polarity. Profile at site C is interpreted as younger than 0.78 Ma, whereas profile B can be substantially older than this datum, similarly to profile at site A sediments. The found corroded pollen grains belonging to herb vegetation *(Dipsacaceae* and *Apiceae* family) typical of dry, steppe-like region were unfortunately of no stratigraphic value.

The profile at site A can be correlated with the Divača profile, not only from the palaeomagnetic point of view, but also from lithological aspect. We suppose, similarly as at Divača, that the fossil caves at Kozina are the result of post-Eocene speleogenetic epoch and its fossilization was connected with tectonic uplift of the area, probably after Messinian *(cf.* Willet *et al.*, 2006). If this hypothesis is close to the reality, the fossilization process could have started at about 5.3 Ma as already expected by Bosák *et al.* (1998, 2000a, 2000b).

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PALEOMAGNETNE RAZISKAVE BREZSTROPIH JAM, KI SO SE ODPRLE MED GRADNJO AVTOCESTE PRI KOZINI, JZ SLOVENIJA

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POVZETEK

Graditev avtoceste med Divačo in Klancem je razkrila številne fosilne in brezstrope jame, zapolnjene z jamskimi sedimenti. Raziskali smo jih s paleomagnetno analizo, s kakršno raziskujemo jamske naplavine na Krasu že od leta 1997 v okviru znanstvenega sodelovanja med Inštitutom za geologijo Akademije znanosti Češke republike, Oddelkom za znanosti o Zemlji in planetih Univerze v Pittsburghu, ZDA, in Inštitutom za raziskovanje krasa ZRC SAZU.

Jamski sedimenti iz profilov pri Kozini so starejši od meje bruhnes/matuyama (0,78 milijona let). Iz razporeditve posameznih magnetocon bi bilo mogoče trditi, da je usedlina starejša od konca dogodka olduvai (1,77 milijona let), saj se magnetostratigrafski profil pri Kozini zaključi z magnetocono inverzne polaritete in vsebuje dve coni normalne polaritete. Zelo primerljiva značaja vrednosti modulov remanentne magnetizacije močno podpirata starostno korelacijo profilov iz fosilnih jam pri Divači in Kozini. Menimo, da je, tako kot v divaškem profilu, jama rezultat messinske speleogeneze, še posebno, če lahko magnetocone normalne polaritete koreliramo s tistimi iz inverzne gilbertove dobe.

Fosilizacija jamskih sistemov je bila povezana s hitrim dvigom ravni baze, potem ko se je pred okoli 5,3 milijona let odprl Gibraltarski preliv in se je Sredozemski bazen spet zapolnil. Nadaljnja fosilizacija je bila posledica sprememb na regionalni ravni baze in hidroloških razmer, ki so nastale s postopnim razvojem površja in neotektonike tega dela Krasa ter zaradi sprememb v višini gladine morja v Sredozemskem bazenu.

Ključne besede: paleomagnetne analize, jamski sedimenti, brezstrope jame, Kozina, Slovenija

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NOVEJŠE UGOTOVITVE PRI RAZISKAVAH NUMULITIN V SLOVENIJI

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IZVLEČEK

Nove raziskave numulitin v Sloveniji prinašajo boljše poznavanje fosilnega inventarja. Marsikatera odpira nove probleme s področja taksonomije, filogeneze in paleogeografije. Tudi v zadnjem času se je pokazalo nekaj takšnih vprašanj, ki so ali bodo še morala biti dokončno rešena.

Ključne besede: numulitine, eocen, Slovenija

NUOVE SCOPERTE NELLA RICERCA DI NUMMULITINI IN SLOVENIA

SINTESI

Le recenti ricerche condotte sui nummulitini in Slovenia hanno portato a una più vasta conoscenza dell'inventario fossile. Tali ricerche aprono quesiti nuovi nei campi della tassonomia, della filogenesi e della paleogeografia. Alcuni di questi recenti quesiti al momento rimangono irrisolti.

Parole chiave: nummulitini, Eocene, Slovenia

UVOD

Pri mnogih raziskavah numulitin se pokažejo zanimivi, delno novi ali dopolnjeni rezultati. Poleg natančnejših poznavanj fosilne favne Slovenije so pomembni stratigrafski podatki, razmišljanja o filogenetskih povezavah, o problemih taksonomije in paleogeografije. To pomeni, da je med množico numulitinskih vrst in podvrst iz Slovenije in drugih prostorov še marsikaj neznanega.

PRIMERJAVA

Fosilna favna iz naših nahajališč se dobro povezuje z nekaterimi tujimi najdišči. Kot primer so zgornjecuisijske numulitine iz fliša v Goriških Brdih in njihova primerjava s španskim nahajališčem Campo v Aragoniji. Iz flišnih plasti pri Vipolžah v Brdih je znanih 13 numulitinskih vrst in podvrst (Cimerman *et al.*, 1974; Pavlovec & Simčič, 1999; Pavlovec, 2004). V Campu so jih od teh ugotovili osem (Schaub, 1966, 1981; Kapellos & Schaub, 1973). Razumljivo je, da je sedem vrst iz Vipolž najdenih tudi v zgornjecuisijskih plasteh pri bližnjem Rožacu (Rosazzo) v Furlaniji (Schaub, 1981).

Na širšem območju Pirenejev so poleg Campa še druga nahajališča s podobno favno kot v Sloveniji. To so med drugim Gan in Pau v zahodni Akvitaniji, kraji v Malih Pirenejih in Boltaña v južnih Pirenejih (Schaub, 1981) in še v drugih pirenejskih nahajališčih (Tosquella & Serra-Kiel, 1998).

Poleg numulitin v tabelah 1 in 2 navaja Tosquella s sodelavci (1998) še naslednje cuisijske vrste, ki jih poznamo tudi iz Slovenije: *Nummulites atacicus* Leymerie, *N. brkiniensis* Khan & Pavlovec, *N. burdigalensis pergranulatus* Schaub, *N. praecursor* De la Harpe, *N. praelaevigatus* Schaub, *N. spirectypus* Doncieux in *N. tauricus* De la Harpe.

Ob tem se ponovno odpira vprašanje, zakaj so slovenska nahajališča glede na fosilni inventar tako blizu Pirenejem. To smo omenili že v zvezi z vremskimi plastmi liburnijske formacije (Pavlovec, 1981b). Takrat je bil dan namig, da je Jadranska mikroplošča morda prišla od zahoda in ne od juga ali jugovzhoda, in je bila zato bliže današnjim Pirenejem oziroma je imela s tem prostorom večjo povezavo. Res pa je, da numulitine iz Pirenejev in soseščine zaradi intenzivnih raziskav v zadnjih letih bolje poznamo kot iz mnogih drugih dežel.

Prav nič ne preseneča, da so bile vse srednjecuisijske vrste in podvrste iz nahajališča Buttrio v Furlaniji (Schaub, 1981) najdene tudi v slovenskih nahajališčih. To so *Nummulites burdigalensis cantabricus* Schaub, *N. burdigalensis pergranulatus* Schaub, *N. kapellosi* Schaub, *N. pavloveci* Schaub, *N. tauricus* De la Harpe, *N. pustulosus* Douvillé, *N. increscens* Schaub, *N.* aff. f*ormosus* De la Harpe, *N.* cf. *subdistans* De la Harpe, *N.* aff. *planulatus* (Lamarck) in *Assilina laxispira* De la Harpe.

Ob tem se odpira še drugo vprašanje, zakaj so v klastitih Slovenije bogata numulitinska nahajališča prav v srednjem cuisiju. Podobno je v nahajališču Buttrio. Če računamo, da so te numulitine prišle v flišno morje iz takratne karbonatne platforme, je vprašanje, zakaj ni toliko teh oblik tudi v enako starih apnencih. Morda so živele bolj proti robu platforme in jih je od tam laže preneslo v flišni bazen?

NOVEJŠE UGOTOVITVE

V Sloveniji se odpirajo še druga vprašanja. Iz zgornjecuisijskih plasti v Brdih poznamo vrsto *Nummulites praelorioli* Herb & Schaub in obliko, ki je tej zelo blizu. Skoraj gotovo jo bo treba opisati kot novo vrsto ali podvrsto (Pavlovec, 2004, 2006b). Sedaj jo označujemo kot *Nummulites* aff. *praelorioli.* Od tipičnih predstavnikov vrste se loči po večji in debelejši hišici in je zelo verjetno prehodna oblika med *N. praelorioli* in lutetijskim *Nummulites boussaci* Rozlozsnik. Tega numulita dobimo še drugod v slovenskih flišnih nahajališčih pa tudi v Istri in morda na Krku (Pavlovec & Klepač, 2003).

Za ugotavljanje natančnejše starosti plasti z različnimi fosili pogosto pomagajo numulitine. Pri Vipolžah je bil prvič v Sloveniji najden polž iz rodu *Velates* (Mikuž & Pavlovec, 2002). Starost tamkajšnjih flišnih plasti smo določili z numulitinami. Podobno je s srednjecuisijsko starostjo morskega ježka *Amblypygus dilatatus* Agassiz & Desor iz kamnoloma Griža pri Rižani (Mikuž & Pavlovec, 2004), kjer sta bili najdeni vrsti *Nummulites archiaci* Schaub in *Assilina laxispira* (De la Harpe). Podobne drobne, vendar zanimive ugotovitve so še drugod. Na Majevici v Bosni je bil prvič na Balkanu najden *Nummulites robustus* Schaub, obenem pa je z numuliti potrjeno, da so tam dejansko tudi spodnjeeocenske plasti (Pavlovec *et al.*, 2005).

Zanimivi so majhni, na videz nepomembni novi podatki. Iz miocenskih prodnikov v severni Sloveniji so bile določene alveoline in numulitine (Drobne *et al.*, 1977), vendar je mogoče najti še kaj novega. Pred kratkim je bila tam ugotovljena pri nas redka vrsta *Assilina plana* Schaub (Pavlovec, 2005). S to obliko smo dokazali spodnjecuisijske apnenčeve prodnike, ki jih v teh miocenskih nanosih dotlej nismo poznali. Po tem sklepamo, da je obstajala karbonatna platforma na območju severno od današnje Slovenije vsaj od spodnjega cuisija do lutetija. Spodnjecuisijske numulitine iz apnencev pri Kotarčah (Guttaring) in Malem Št. Pavlu (Klein St. Paul) na Koroškem omenja tudi Schaub (1981).

Iz okolice Kuteževega pri Ilirski Bistrici so nahajališča numulitin iz več stratigrafskih horizontov: iz spodnjega in zgornjega cuisija ter iz prehoda cuisij – lutetij (Pavlovec, 2003b). Tako različna starost flišnih plasti na majhnem prostoru kaže na močno tektonsko aktivnost, na prelome, gubanja in narivanja. Med tamkajšnjo favno

sta bili vrsti *Ass. plana* Schaub in *Assilina karreri* (Penecke) najdeni do takrat prvič pri nas. V teh in še drugih nahajališčih je dokaj pogosta podvrsta *Assilina marinellii marinellii* (Dainelli). Iz srednjecuisijskega fliša pri Podgradu na južni strani Brkinov je bila opisana (Khan *et al.*, 1975) podvrsta *Ass. marinellii similis* (Khan & Pavlovec) (Sl. 1). Pojavil se je že dvom, da sta to res dve podvrsti ali morda sodita v variacijsko širino ene same (Pavlovec, 2003a, 2004). Na podlagi preučevanj numulitin iz Podveležja v Hercegovini (Sl. 2) ugotavljamo, da sta to res dve različni obliki (neobjavljeno).

Že večkrat obravnavano taksonomsko vprašanje vrste ali podvrste pri fosilih je odprto. Schaub (1981) je bil pri numulitinah zagovornik podvrst, ki se včasih komaj ločijo od tipične vrste. Po drugi strani je nekajkrat prištel isti vrsti primerke z dosti različnimi taksonomskimi značilnostmi. Tako sva v istem letu opisala novo spodnjelutetijsko obliko, Schaub (1981) kot *Assilina spira abrardi* (Sl. 3), Pavlovec (1981a) kot *Assilina istrana*. Ob pogovorih, kako revidirati to dvojnost, je Schaub predlagal, da obdržimo ime *istrana*, vendar je vztrajal pri podvrsti oblike *spira*, torej bi bila *Ass. spira istrana*. Do skupne objave tega dogovora do smrti prof. H. Schauba žal ni prišlo in tako tudi sam uporabljam njegovo oznako *Ass. spira abrardi* in je *Ass. istrana* sinonim.

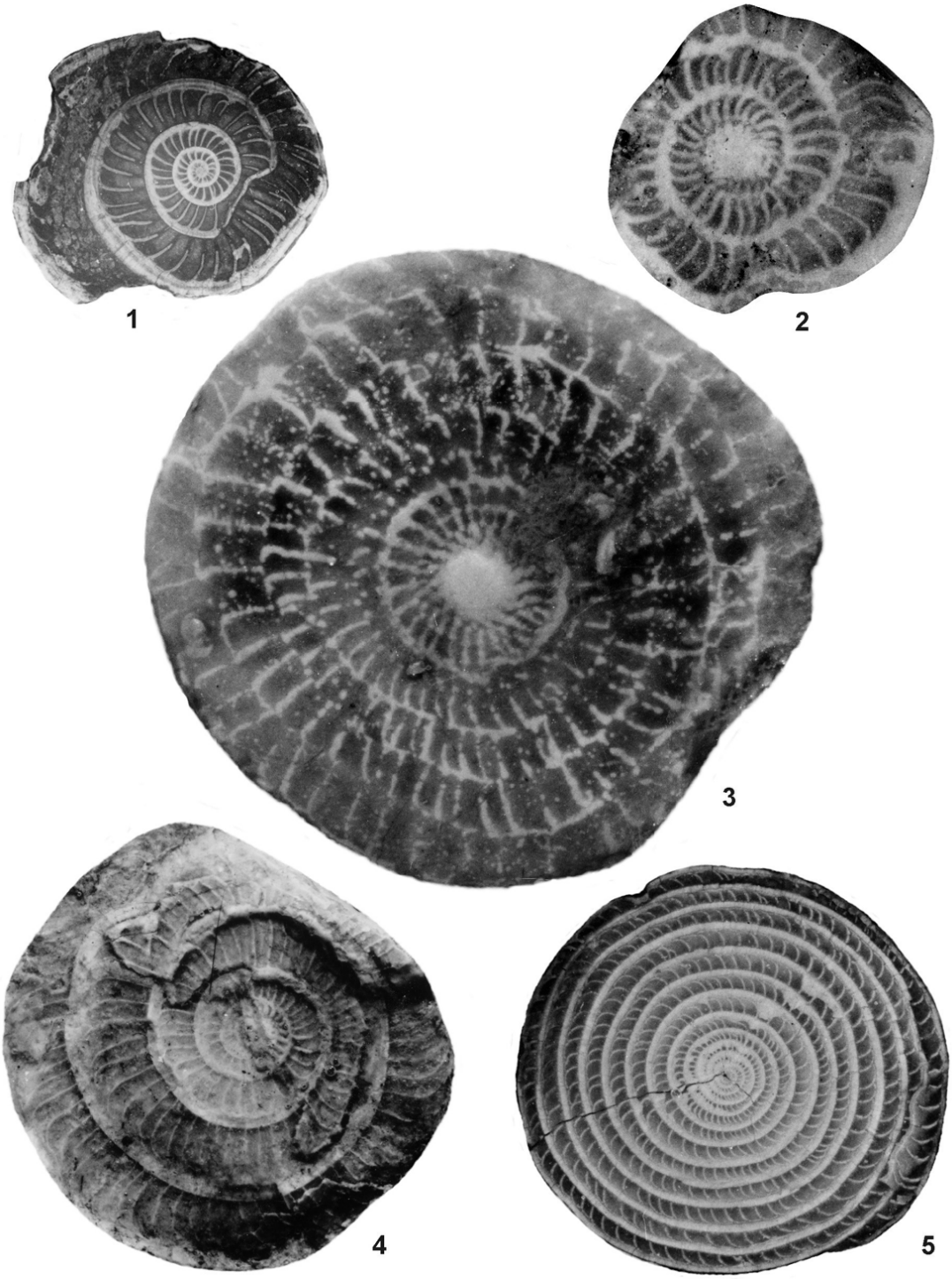
Z našimi prostori je povezan še drug primer vprašanja vrste ali podvrste. V Istri je precej pogosta spodnjelutetijska *Assilina praespira* Douvillé. V nekoliko mlajših spodnjelutetijskih plasteh se pojavi *Assilina maxima* (Pavlovec,1969). Po Hottingerjevem mnenju (Hottinger, 1977) je *Ass. maxima* podvrsta oblike *Ass. praespira*, torej *Ass. praespira maxima*. Pozneje je bila ugotovljena še vmesna oblika *Assilina monacensis* (Pavlovec, 1993) (Sl. 4). Zato je upravičeno imeti obliko *maxima* za samostojno vrsto. To je potrjeno še iz stratigrafskega vidika, saj se je v spodnjem lutetiju najprej pojavila *Ass. praespira*, nato *Ass. monacensis* in končno *Ass. maxima,* čeprav so potem živele vse tri še skupaj (Majcen, 1986, 1987; Pavlovec & Majcen, 1986; Pavlovec, 1993).

Pri Dolnjem mlinu v Vipavski dolini je bil najden v flišu kos apnenca iz olistostrom. V njem je bila prvič v Sloveniji ugotovljena vrsta *Nummulites haymanensis* Schaub (Pavlovec & Bačar, 2004). Poleg nje je *Nummulites bombitus* Hottinger, ki ga pri nas dotlej nismo pogosto našli. V zadnjem času je bil *N. haymanensis* ugotovljen tudi v flišu Vipavske doline, *N. bombitus* pa v apnencih te doline (neobjavljeno). Takšni operkulinoidni numuliti, kot sta *N. bombitus* Hottinger in njemu zelo podoben *Nummulites spirectypus* Doncieux, so v nekaterih plasteh pogosti. Zadnjega smo našli v velikem številu v apnencu iz olistostrom pri Planini nad Ajdovščino. V olistolitu pri Dolnjem mlinu je prvič pri nas ugotovljena numulitna združba *Nummulites ornatus* Schaub, *N. bombitus* Hottinger, *N. haymanensis* Schaub in *Nummulites subdistans* De la Harpe.

Nekaj zanimivih ugotovitev je tudi med preostalim preiskanim gradivom (Pavlovec, 2006a). Pri Lokavcu nedaleč od Ajdovščine je v srednjecuisijskih olistostromah prvič na tem prostoru ugotovljena vrsta *Assilina escheri* (Hottinger), ki jo poznamo iz Furlanije in avstrijske Koroške. *Nummulites brkiniensis* Khan & Pavlovec (Khan *et al.*, 1975) je bil najden na več mestih v Sloveniji. Zunaj tega območja je znan iz Pirenejev (Tosquella & Serra-Kiel, 1998) in sedaj tudi iz Hercegovine (neobjavljeno) (Sl. 5). Vse bolj se kaže, da so vrsta *N. brkiniensis* Khan & Pavlovec ter njej nekatere zelo podobne oblike pogostejše, kot smo mislili doslej. Pri Trnovem (Ilirska Bistrica; Pavlovec, 2006b) je v zgornjecuisijskem flišu *Nummulites kapellosi* Schaub, ki je bil doslej pri nas najden v apnencih pri Ivartniku nedaleč od Kotelj na Koroškem in v flišu v Postojni. Iz Goriških Brd prvič opisana vrsta *Nummulites quasilaevigatus* Pavlovec je bila najdena tudi v flišu pri Trnovem, nadalje v Furlaniji, Dobrinju na Krku, Campu v Španiji in v Iranu.

ZAKLJUČEK

Omenjeni primeri kažejo, da fosilno numulitinsko favno in njene združbe iz Slovenije z novimi raziskavami stalno dopolnjujemo in da dobljeni stratigrafski podatki prinesejo nova razmišljanja in probleme. Po drugi strani se povezujejo favne iz raznih prostorov, kar po našem mnenju ne kaže na izrazite numulitinske favnistične province. Te so bolj odvisne od razlik v okolju, kar je vplivalo na večjo ali manjšo razširjenost posameznih vrst. Nekatere numulitinske oblike so potrebovale za optimalni razvoj nekoliko specifične življenjske razmere (Pavlovec, 2003a). Večkrat je bilo že omenjeno vprašanje, zakaj so nekatere numulitine v flišu dokaj pogoste, medtem ko jih iz enako starih apnencev ne poznamo ali so tam zelo redke. To preseneča tudi zato, ker so morale biti prenesene v flišni bazen prav iz karbonatne platforme. Tudi v tem pogledu je poznavanje numulitin pri nas še pomanjkljivo. Dejansko včasih drobne ugotovitve privedejo do novih spoznanj, in to ne samo v smislu spoznavanja fosilnega inventarja na Slovenskem, marveč tudi do drugih zanimivih razmišljanj.



Sl. 1 / Fig. 1: *Assilina marinellii similis* ***(Khan & Pavlovec). Podgrad, srednji cuisij / Middle Cuisian (5x).***
Sl. 2 / Fig. 2: *Assilina marinellii similis* ***(Khan & Pavlovec). Podveležje, Hercegovina, srednji cuisj / Middle Cuisian (5x).***
Sl. 3/ Fig. 3: *Assinila spira abrardi* ***Schaub. Suha Ričina, Krk, spodnji lutetij / Lower Lutetian (5x).***
Sl. 4 / Fig. 4: *Assilina monacensis* ***Pavlovec. Stena pri Dragonji, spodnji lutetij / Lower Lutetian (2x).***
Sl. 5 / Fig. 5: *Nummulites brkiniensis* ***Khan & Pavlovec. Podveležje, Hercegovina, srednji cuisij / Middle Cuisian (5x).***

THE NEW FINDINGS IN NUMMULITIN RESEARCH IN SLOVENIA

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SUMMARY

There is a great similarity between nummulitin species of Slovenia and those of the Pyrenees. It is possible that the Adriatic microplate in fact originated from the west, as already claimed. In our opinion, the comparison of nummulitin associations from different regions basically shows various environments, appropriate for different associations that needed some specific ecological conditions.

In 1981, the same assilina was described, the first as Assilina spira abrardi *and the second as* Assilina istrana. *Both authors agreed to publish their findings and to describe it as* Ass. spira istrana. *Schaub insisted that* "istrana" *is subspecies of* As. spira. *As Schaub died before the article was prepared, we use the name* Ass. spira abrardi. *So* Ass. istrana *is a synonym.*

From some Slovene localities, the form described as Nummulites *aff.* praelorioli is known. *It differs from typical* Nummulites praelorioli *by larger and thicker test. It is probably an interform between* N. praelorioli *and* N. boussaci.

It is still not clear why there are such nummulitin species in some Cuisian flysch localities that are not known from limestones of the same age. Is it possible that such nummulitins lived on the edge of carbonate platform?

Key words: nummulitins, Eocene, Slovenia

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IN MEMORIA DEL PROF. MARIO SPECCHI

Mario Specchi è nato a Trieste nel marzo del 1935, a Trieste ha condotto i propri studi e si è laureato in Scienze Naturali. Immediatamente dopo la laurea, nel 1964, è nominato assistente incaricato presso l'Ateneo triestino e, l'anno successivo, assistente ordinario. E' stato, infatti, il primo assistente incaricato dal Prof. Ghirardelli presso l'allora Istituto di Zoologia ed Anatomia comparata. Nel 1981 viene dichiarato idoneo al concorso per professore associato nella disciplina Zoologia, nel 1986 è vincitore di un concorso di prima fascia e viene chiamato dall'Università di Messina a ricoprire la Cattedra di Zoologia per Scienze Naturali.

Resta a Messina dal 1987 al 1990 ed, in seguito, viene nuovamente richiamato a Trieste a ricoprire per trasferimento la Cattedra di Zoologia rimasta vacante, per i raggiunti limiti di età, del suo Maestro Prof. Ghirardelli.

Fin dagli inizi della sua carriera svolge un'intensa attività di ricerca, per lo più incentrata sullo studio del plancton marino e, più in particolare, sulla sistematica, distribuzione e biologia dei Cladoceri marini. Gli studi riguardanti il plancton, in particolare quello dell'Alto Adriatico, vengono svolti in collaborazione con diversi ricercatori italiani, sloveni e croati.

L'interesse scientifico nei confronti del mare nel 1976 lo porta ad essere eletto presidente del Comitato plancton della Società Italiana di Biologia Marina e, nello stesso anno viene nominato direttore del Laboratorio di Biologia Marina di Trieste. Nel 1978 viene iscritto all'Ordine dei Giornalisti del Friuli Venezia Giulia in qualità di direttore responsabile della rivista scientifica "Nova Thalassia" edita dal Laboratorio di Biologia Marina.

Anche nel corso della sua permanenza a Messina, si occupa attivamente del Laboratorio di Idrobiologia di Ganzirri, del quale, assieme al prof. Guglielmo, chiede alle Autorità Accademiche la ristrutturazione, per consentire ai membri del Dipartimento, ma anche agli studiosi italiani e stranieri, di avere una sede a mare rimessa a punto e funzionale.

Comunque già dagli inizi degli anni '70, le ricerche, precedentemente condotte esclusivamente in ambito marino, iniziano ad interessare anche le acque interne e, più in particolare, il plancton lacustre, la fauna ittica e la fauna macrobentonica. Nel 1973 entra a far parte del Consiglio Direttivo dell'Ente Tutela Pesca del Friuli Venezia Giulia dove fino alla sua scomparsa seguirà, in qualità di "esperto biologo" l'attività scientifica. Nel 1981, per conto dello stesso Ente fonda un piccolo laboratorio di Idrobiologia (l'attuale Acquario d'acqua dolce di Ariis di Rivignano), del quale diventa responsabile scientifico. Nel 1985 è Socio fondatore dell'A.I.I.A.D. (Associazione Italiana Ittiologi Acqua Dolce) di cui per diversi mandati viene nominato presidente.

Della sua attività resta testimonianza in circa duecento pubblicazioni scientifiche. I suoi colleghi e gli studenti lo ricordano come un uomo dai molteplici interessi, dalle idee originali, appassionato ed instancabile negli studi, ma anche come una persona di grande bontà.

Donatella Del Piero & Elisabetta Pizzul

PROF. DR. MIROSLAV ZEI : ŽIVLJENJE, DELO IN DOSEŽKI

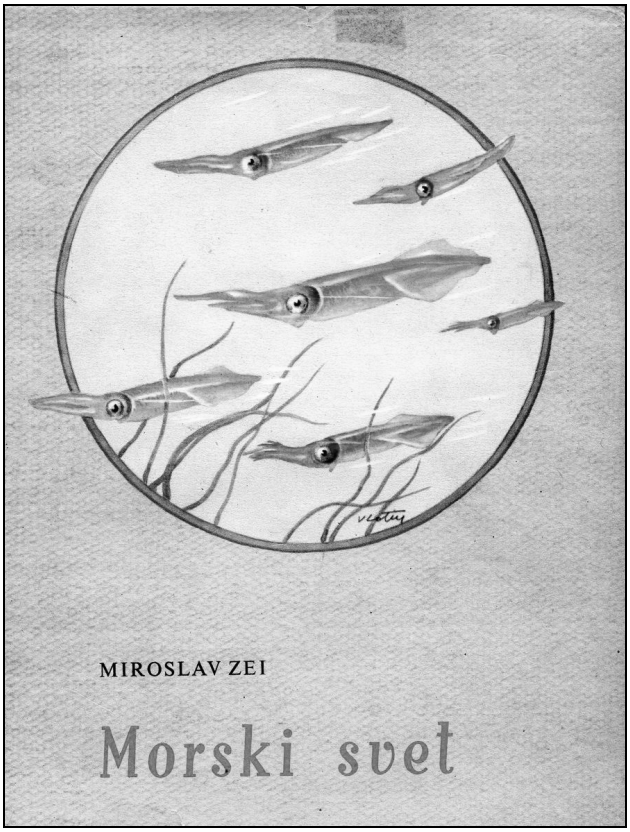
Rodil se je 25. julija 1914 v Nabrežini pri Trstu, materi Rozaliji roj. Cotič in očetu Hermanu. Ko je Trst l. 1920 prišel pod Italijo, se je družina zaradi znanih razmer preselila v Slovenijo, najprej malo razočarana v Ljubljano, nato pa za stalno v Maribor. Tam se je tudi šolal ter na Realni gimnaziji maturiral leta 1932, ko je vpisal študij biologije na Filozofski fakulteti Univerze v Ljubljani. Diplomiral je leta 1936, in začel kar takoj z vso paro delovati na področjih ihtiologije, ribiške biologije in biološke oceanografije – v strokah, ki jim je ostal popolnoma predan do danes, torej skoraj 70 let svojega znanstvenega, akademskega in pisateljskega udejstvovanja. Morje mu namreč ne pomeni le poklicne usmeritve, marveč je tudi eno izmed velikih ljubezni njegovega življenja. Seveda, nostalgična usedlina otroških spominov na tržaško morje pa sanjarjenja o širnih oceanih, ki mu jih je v svojih pripovedih pričaral oče – strojnik na ladjah avstrijske vojne mornarice – so že v mladosti zbudili njegovo živahno zanimanje za morje in njegove skrivnosti. Odločilno pa ga je že med študijem k temu

tudi poklicno usmeril njegov "akademski mentor" profesor Jovan Hadži, ki je bil tudi sam zelo navezan na morje in na morske organizme, na katerih je opravil svoja najpomembnejša raziskovanja. Prav on mu je tudi pomagal, da se je lahko skoraj takoj po diplomi že leta 1937 zaposlil na Inštitutu za oceanografijo in ribištvo v Splitu, kjer je ostal, najprej kot asistent, nato pa kot znanstveni sodelavec, do leta 1948.

To obdobje – imenujemo ga lahko kar "splitska etapa" – je bilo zelo pomembno, ne le za njegovo osebno znanstveno kariero, marveč tudi za stroko, ker se je tedaj, predvsem po njegovi zaslugi, začel oblikovati nov pristop k raziskavam Jadrana in njegovega ribjega bogastva ter tako tudi uvajanje smotrnega, ribjim populacijam neškodljivega ribištva. Njegove takratne raziskave in publikacije o pridnenih ribjih naseljih so namreč pomenile pionirske korake vtirjenja sodobne ribiške biologije na Jadranu in tudi drugod po Mediteranu. To delo, oziroma z njim pridobljena bogata zbirka rib, pa sta mu, kot "stranski produkt", omogočila za bazično ihtiologijo zelo pomembno revizijo prej dokaj konfuzne sistematike giric (fam. Maenidae, ref. 1940a, 1941 in 1951) ter odkritje zamenjave spola pri teh in drugih ribjih vrstah (ref. 1942, 1949c in 1961), ki je bilo tako pomembno, da je prišlo tudi v specializirane učbenike ihtiologije in primerjalne fiziologije živali.

Sledilo je obdobje 1948–1962, ko je bil zaposlen, najprej kot izredni, od leta 1954 pa kot redni profesor pri Zooloških inštitutu Naravoslovne in kasneje Biotehniške fakultete Univerze v Ljubljani. Po upokojitvi prof. Hadžija je leta 1956 prevzel vodstvo tega inštituta in katedre, bil pa je tudi prvi direktor Inštituta za biologijo, ki je bil leta 1960 ustanovljen s prvotnim namenom medfakultetnega združevanja bioloških raziskovalnih programov celotne univerze. V dveh mandatih je bil tudi dekan in je s tega položaja skušal mdr. preprečiti nesmotrno zamisel o premestitvi biologije iz Naravoslovne v Biotehniško fakulteto. Ta "subverzivna" akcija pa mu žal ni uspela, pač pa si je pri partiji in rektorju nabral kar nekaj črnih pik. No, mogoče se je kasneje tudi zaradi tega laže odločil sprejeti ponujeno zaposlitev pri OZN oz. FAO.

Tudi njegovo pedagoško delo je bilo v tem obdobju zelo pestro in zahtevno. Poučeval je namreč kar štiri redne predmete: primerjalno anatomijo vretenčarjev, biologijo strunarjev, evolucijo in ekologijo morja. Njegova predavanja so bila sicer zelo strnjena in zahtevna, toda živahna, duhovita in privlačna za študente – skoraj tako kot tečaji morske biologije, ki jih je vsako poletje prirejal na Institutu Jugoslavenske akademije znanosti i umjetnosti za biologiju mora v Rovinju. V obdobju 1951–1960 je namreč kot honorarni direktor to ustanovo vodil med drugim tudi v smeri bodoče "internacionalizacije", kar pa v razmerah tedanje SFRJ še zdaleč ni bilo preprosto, vendar je začetni odpor domiselno premostil z organizacijo prav takšnih tečajev za študente biologije s tujih evropskih univerz.



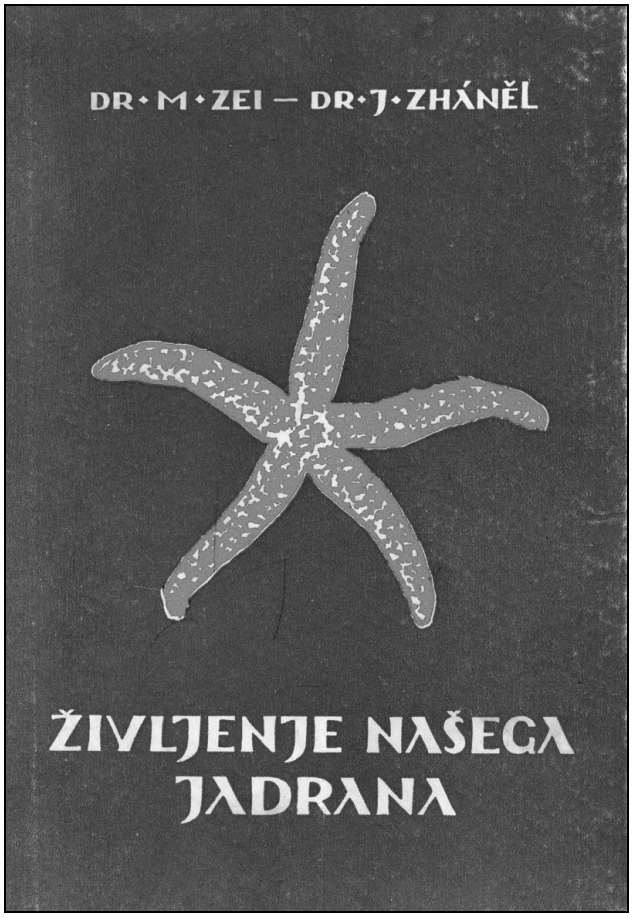
Ob koncu poročanja o tem obdobju se moramo hvaležno spomniti tudi na to, da je v letih 1960–1962 predsedoval Društvu za raziskovanje morja in podvodno tehniko ter da je brez pomislekov zastavil ves svoj vpliv v prid društvenega navidezno pustolovskega načrta za "1. jugoslovansko odpravo na Rdeče morje in v Etiopijo", ki je seveda odlično uspela. Tako je posredno tudi na tak način botroval dejavnostim, ki so dopolnjevale konvencionalno visokošolsko in raziskovalno delo ter tako, predvsem pa s svojim osebnim vplivom na svoje študente, bistveno pripomogel k temu, da je majhna Slovenija ob pljunkcu Jadrana dala kar precej cenjenih raziskovalcev morja, med njimi štiri, ki so dolgoletno delovali za OZN kot nosilci pomembnih projektov organizacij FAO in UNESCO na morjih štirih kontinentov.

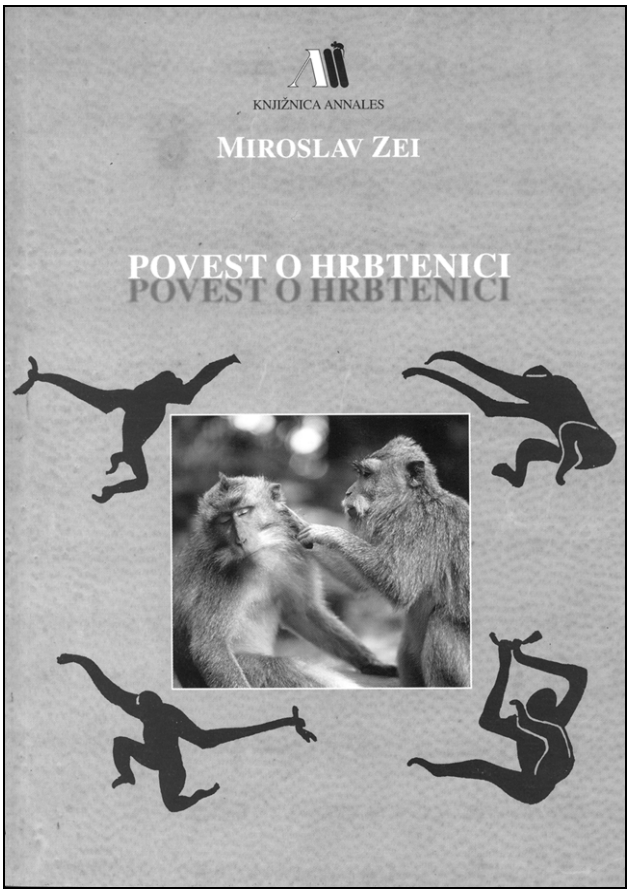
Prof. Zei je bil seveda prvi, ki je šel po tej poti. Kot ekspert FAO za ribiško biologijo in oceanografijo ter direktor projektov za razvoj morskega ribištva, je v Afriki delal za OZN zdržema 13 let, najprej na različnih projektih za Gano (1962–1970) in Tunizijo (1970–1973), nato je pa v obdobju 1973–1975 na sedežu FAO v Rimu in prek Regionalnega urada v Dakarju vodil t.i. CECAR Project. Le-ta je deloval v sestavi Globalnega projekta za razvoj morskega ribištva, za katerega je pokrival regijo centralnega Vzhodnega Atlantika in usmerjal vse nacionalne ribiške organizacije od Maroka do Zaira.

Kljub znanemu načelu, da FAO od svojih sodelavcev sploh ne pričakuje znanstvenih publikacij, pač pa predvsem takšne rezultate, ki so hitro in neposredno uporabni za razvoj praktičnega ribištva, je prof. Zei publiciral tudi v obdobju svoje "FAO etape". Objavil je sicer malo del (ref. 1965, 1966, 1969, 1970 in 1975), ki pa so zelo pomembna za atlantsko morsko ribištvo po eni ter splošno za ribiško biologijo sardel in sorodnih vrst rib po drugi strani.

Kmalu potem ko se je leta 1975 pri OZN upokojil in se iz Rima preselil v Portorož, je leta 1977 prevzel mesto honorarnega predstojnika tamkajšnje Morske biološke postaje (MBP). Kar hitro mu je uspelo premostiti notranjo krizo, v kakršni je bila tedaj MBP, hkrati pa je s svojo avtoriteto bistveno pospešil financiranje adaptacije in graditve novih prostorov v obmorski stavbi na Fornačah pri Piranu, kamor se je potem MBP preselila že leta 1980.

Toda ta stavba se je gradila še z drugim osnovnim namenom, da bi namreč v njej omogočila tudi delovanje Regionalnega podiplomskega centra za študij ekologije Mediterana, ki ga je Medvladna oceanografska komisija (IOC) pri UNESCO poverila v izvedbo Univerzi v Ljubljani in MBP, do česar pa zaradi nekaterih, tudi banalnih vzrokov žal ni prišlo.





Poleg tega je prof. Zei v času svojega delovanja na MBP (1977–1983) z mnogo truda – in nemalo nasprotovanja – poskušal tam uveljaviti uporabna ribiško-biološka raziskovanja, predvsem v smeri razvoja marikulture morskih rib in školjk, kar pa zaradi brezbrižnosti in nesmiselnih nasprotovanj ni dalo pričakovanih uspehov.

Kljub temu pa je ostal v stroki tudi tedaj izjemno aktiven. Tako se je potrudil obnoviti naziv rednega profesorja in je v obdobju 1976–1985 predaval predmeta "Ihtiologija z ribiško biologijo" in "Morska biologija". Od leta 1980 do 1989 pa je bil glavni predavatelj cirkularnega Mednarodnega tečaja ribiške oceanografije in biologije za slušatelje afriških, azijskih in latino-ameriških držav v razvoju, ki ga je vsako poletje organiziral Zavod SFRJ za mednarodno sodelovanje na Inštitutu za oceanografijo in ribištvo v Splitu. Po naročilu tega zavoda je opravil tudi misije tehnične pomoči za razvoj ribištva v Sao Tome-Principe (1980) in na Zanzibarju (1982).

Po letu 1983, ko na MBP ni imel več nobenih funkcij, je tudi precej več publiciral, in sicer znanstvene ter strokovne članke in knjige (ref.: 1983, 1984a, b, c, 1989, 1996 in 1999) in poljudnoznanstvene knjige (ref.: 1983, 1987a, b, 1988 in 1999), v katerih je med drugim navedel in uredil vsa slovenska imena vrst morskih rib, isto pa je prispeval tudi – kot terminološki svetovalec – za Slovar slovenskega jezika (SAZU, 1970–1991). No, pa tudi malo več pravega pokoja si je vzel, najraje na svoji barki med kornatskimi otoki, skorajda do konca svojega bogatega življenja, ko je novembra 2006 umrl.

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